AFOSR - 88 - 0065

EVALUATION OF SOLAR FRARES AND ELECTRON PRECIPITATION BY NITRATE DISTRIBUTION IN ANTARCTICA

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ANNUAL TECHNICAL REPORT

November 1, 1990 to October 31, 1991
November 1, 1990

Contracting Officer: Capt. Helen R. Tyson
Program Manager: Dr. Henry R. Radoski

Prepared for

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
BOLLING AFB, D.C. 20332-6448

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE

3. REPORT TYPE AND DATES COVERED
ANNUAL 1 Nov 90 TO 31 Oct 91

4. TITLE AND SUBTITLE
A NITRATE SIGNAL OF SOLAR FLARES IN POLAR SNOW AND ICE

5. FUNDING NUMBERS
GR - AFOSR-88-0065
PE - 61102F
PR - 2311
TA - AI

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
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10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release;
distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Most of the time devoted to project research was spent in Antarctica. A firm core was drilled by hand to a depth of 29 meters at Windless Bight on the Ross Ice Shelf. The main result is that all of the major peaks identified as resulting from ionization caused by SPEs that were found in the 1988-89 core could also be identified in the analytical sequence from the 1990-91 core. Following the Antarctic field season, a set of snow samples were obtained that had been collcted by the International Trans-Antarctica Expedition. The analysis of these samples showed nitrate flux that correlates closely with known spatial distribution of electron precipitation in the south polar region. A new apparatus has been build for field analysis on a continuous basis of nitrate and conductivity in a melt derived from the vertical melting of ice cores.

14. SUBJECT TERMS

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UNLIMITED

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EVALUATION OF SOLAR FRARES AND ELECTRON PRECIPITATION BY NITRATE DISTRIBUTION IN ANTARCTICA

Summary

During the beginning of the funding period, most of the time devoted to project research was spent in Antarctica (November 1990 to mid January 1991). A firn core was drilled by hand to a depth of 29 meters at Windless Bight on the Ross Ice Shelf. This dill site was located about 10 km from that of the 1988-89 core. The main result of the study is that all of the major peaks identified as resulting from ionization caused by SPEs in 1972, 1946, and 1928 that were found in the 1988-89 core could also be identified in the analytical sequence from the 1990-91 core. Dating of the new core is based mainly on the snowfall record from nearby McMurdo Station, snow stratigraphy and high resolution conductivity data. Following the Antarctic field season, we were able to obtain a set of snow samples that had been collected by the chinese member of the International Trans-Antarctica Expedition that crossed the entire continent on foot in a 7 month period in 1989-90. The analysis of these 95 samples showed nitrate flux that correlates closely with known spatial distribution of electron precipitation in the south polar region. A new apparatus has been built for field analysis on a continuous basis of nitrate and conductivity in a melt stream derived from the vertical melting of ice cores. Such a system will provide an improved method for dating the individual ice layers, as well as maximum accuracy and precise matching between the nitrate and conductivity profiles.

EVALUATION OF SOLAR FRARES AND ELECTRON PRECIPITATION BY NITRATE DISTRIBUTION IN ANTARCTICA

I. Distribution of Nitrate Content in the Surface Snow of the Antarctic Ice Sheet Along the Route of the 1990 International Trans-Antarctica Expedition

Previous work showed that nitrate measured at very high resolution (1.5 CM) in snow depositional sequences in Antarctica could be correlated with short term phenomena such as solar proton events (Dreschhoff and Zeller, 1990). It was clear that deposition of the ionization products in the snow is strongly dependent upon precipitation and atmospheric conditions during and immediately after the event. Information about the geographic distribution of the nitrate fallout over Antarctica was limited to only a few sites however. A unique opportunity to examine this aspect of the nitrate distribution and to test the hypothesis that atmospheric ionization from solar charged particles is responsible for a significant portion of nitrate was presented to us by a set of surface snow samples collected by the International Trans-Antarctica Expedition foot traverse.

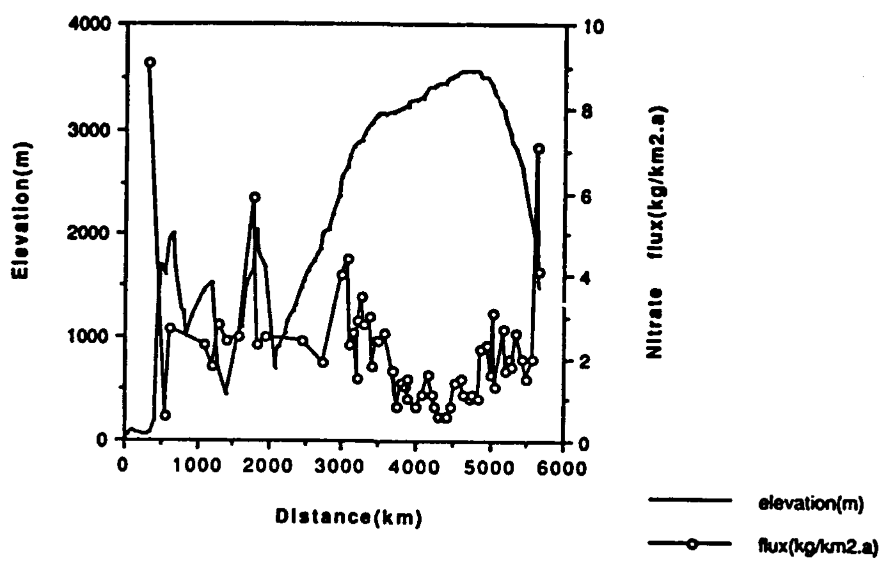

Figure 1. Nitrate flux in surface samples across the Antarctic continent sampled during the International Trans-Antarctica Expedition.

The set of 95 samples of the upper 25 cm was collected by Qin Dahe of the Chinese Academy of Science at roughly equal distances along the 5736 kilometer route from 27 July, 1989 to 3 March, 1990. Samples are distributed along a track from 65°05'S, 59°35'W, through 90°S, to 66°33'S, 95°39'E, which represents geomagnetic latitudes ~50 S, West longitude, to ~77°S, East longitude. The profiles of nitrate concentration and flux along the route were plotted and indicate that (especially at the higher elevation of the polar plateau) the distribution is, at least in part, controlled by the precipitation of electrons. The highest flux was found in areas where electron precipitation is known to be unusually high (Sheldon, et al., 1987). These results are shown in Figure 1, and details of this work are presented in Appendix A. Further interpretation of this data is anticipated. As pointed out by D. Smart and M. A. Shea (personal communication, 1991), data such as the auroral boundary index compiled by Madden and Gussenhoven (1990) could result in a more comprehensive explanation of variation in that portion of the nitrate profile that traverses the area surrounding the South Pole Station. A preliminary discussion of the nitrate distribution relative to electron precipitation in the south polar region will be presented at the AGU Fall meeting, San Francisco, 1991 (See Appendix B).

II. Results from Windless Bight, Antarctica on Major Solar Flares during Solar Cycles 22 to 14.

During the 1990-91 field season in Antarctica we drilled 29 meters of firn core by hand and made simultaneous analyses for both nitrate and liquid conductivity using a Beckman Model 160 UV spectrophotometer and an Orion Model 160 conductivity meter. The detector cells were arranged in sequence so that flow from the UV absorption cell was discharged directly int(the conductivity cell and readouts were obtained simultaneously. The seqence for nitrate could be compared with that obtained during the 1988/89 Antarctic field season in which a 62 year high resolution analytical sequence from the Ross Ice Shelf showed strong anaomalies that could be directly associated with specific manjor solar flare events (Dreschhoff and Zeller, 1990). This profile, Figure 2a, represented cycles 16 through 21. Large solar proton events (SPEs) were easily detectable in cores sampled continuously at high resolution (1.5 cm) and these primary peaks were over 6 standard deviations above the mean (in Figure 2 the peaks are labeled A, B and C). At this resolution, secondary peaks caused by meteorological effects associated with individual snow storms (year 1988) also occurred at intensity levels up to a maximum of 4 standard deviations above the mean. It was found that identifiable peaks in the nitrate concentration are critically dependant on factors such as the timing of the event relative to the polar winter night and the local meteorology that influences snow accumulation.

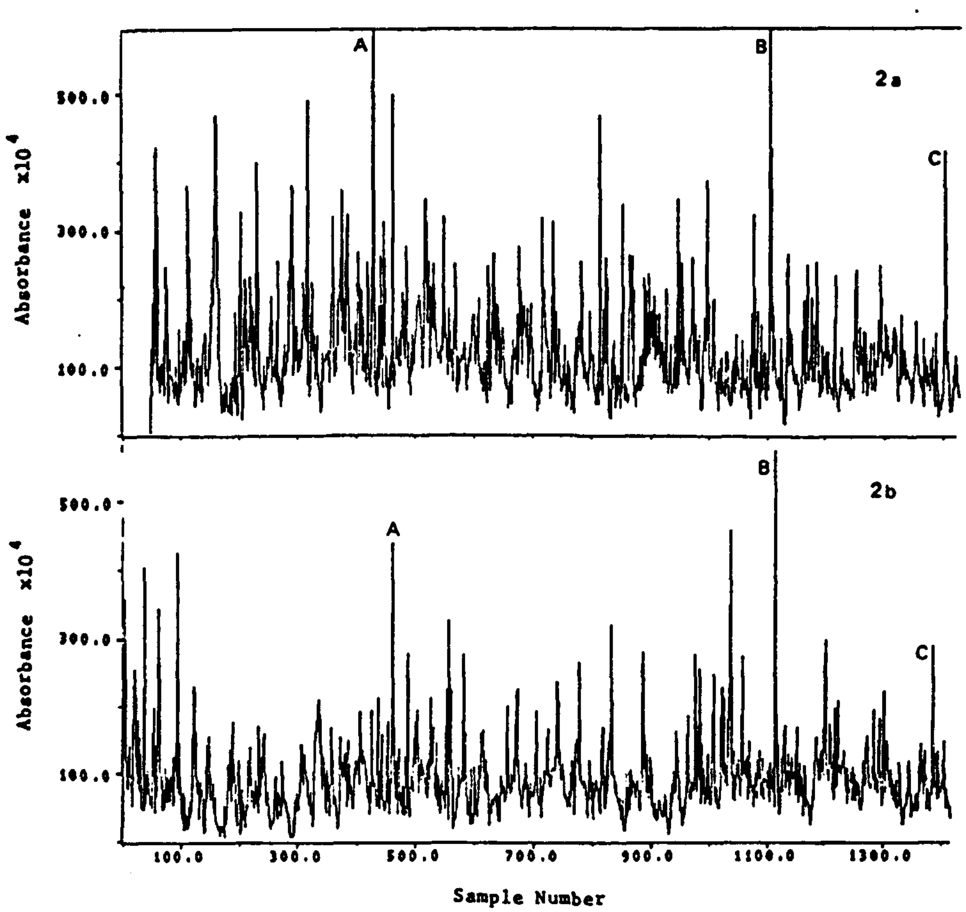

Figure 2. Nitrate concentrations in relative units (UV absorbance) at two drill sites at Windless Bight, for Antarctic season 1988-89 (2a) and Antarctic field season 1990-91 (2b). A new Beckman Model 160 which is less sensitive by about 30 % was used in 1990-91. The two sequences are separated by ~ 10 km and represent ~ 21 meters of firn core and a time period of ~ 62 years. Local meteorology and ice flow produce differences in snow deposition and snow compaction changes progressively through time resulting in differences in thickness of yearly layers. Nevertheless, the primary concentration peaks associated with flares in 1972, 1946, and 1928 are clearly visible (labeled as A, B and C). Dating has been accomplished by snowfall records, visible snow stratigraphy, D/H variations and conductivity.

Furthermore, after deposition, diagenetic processes related to the compaction of the snow tend to distort the shape of the original nitrate signal by diffusion within ice crystals and by mixing that occurs as the crystals grow together in the compaction process.

These processes introduce a randomization factor that increases through time and plastic flow of the ice. Nitrates scavenged from the atmosphere (mostly troposphere) are thought to reside on the outer surfaces of the snow crystals (W. H. Zoller, Personal communication, 1991). If this is true, it

might be expected that nitrate from this source would be subject to major redistribution during the recrystallization processes that occurs in surface and near surface snow associated with compaction. On the other hand, nitrate from stratospheric sources is probably incorporated into snow crystals by processes that cause a major difference in distribution within the snow crystals.

Polar stratospheric clouds (PSCs), in some cases, consist of very high concentrations of nitric acid (McElroy et al., 1988). We hypothesize that precipitating snow crystals may contain nucleation centers derived from PSC particles. Once they enter the troposphere, these nucleation centers are surrounded by condensing ice and may survive the diagenetic process without significant redistribution. For this reason, nitrate peaks originating from PSCs or other sources in the stratosphere, like those identified as A, B, and C, are more likely to retain their identity. Some preliminary evidence for this hypothesis is presented in Figure 2b. This is the data series acquired during 1990/91 Antarctic field season equivalent in depth to the record from 1988-89. The complete record is shown in Figure 3a. It is important to recognize that these

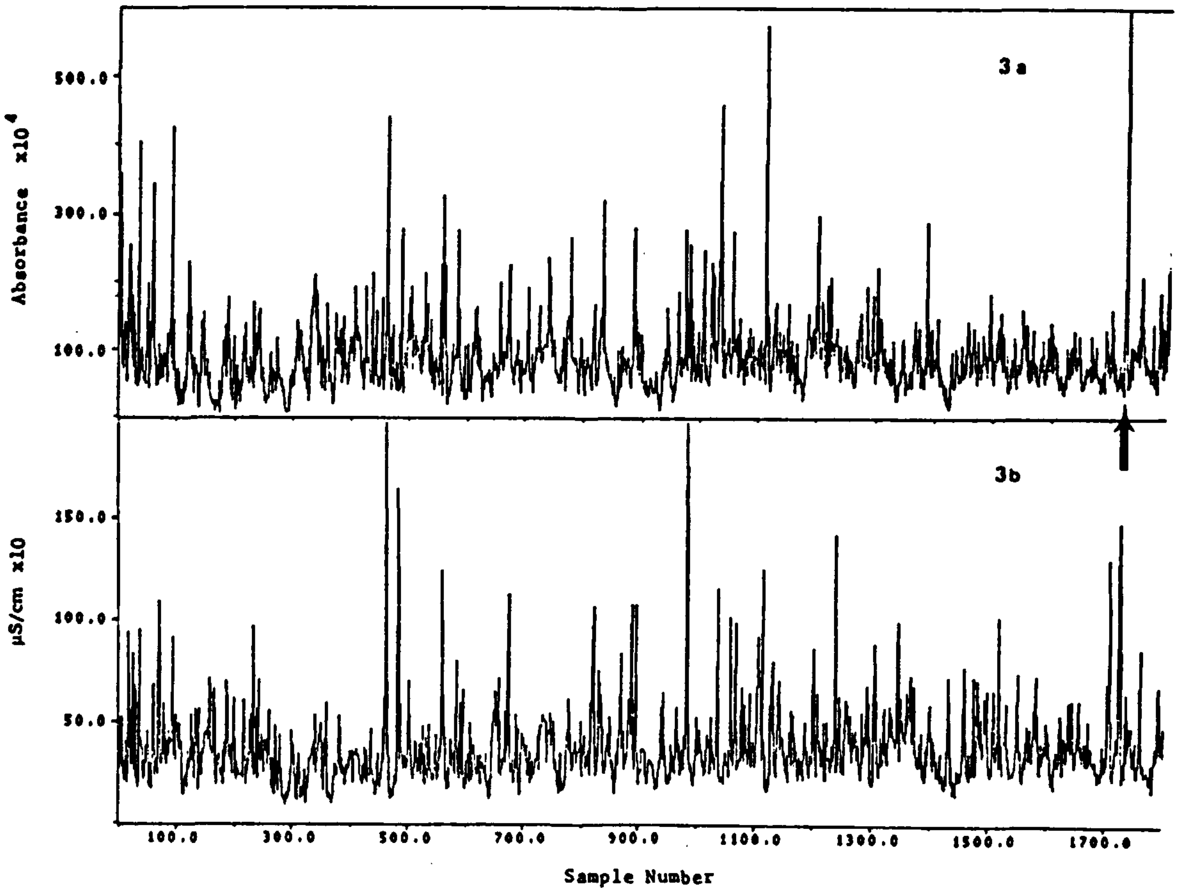

Figure 3. Complete 29 meter firn core from the 1990-91 field season showing nitrate concentrations in relative units of UV absorbance (3a) and liquid conductivity (3b). Readouts of nitrate and conductivity were obtained simultaneously on the same sample. Arrow indicates position of dust layer.

primary peaks are present in both sequences in spite of the 10 kilometers distance that separates the drill sites and the differences in meteorological conditions and ice flow patterns in the ice shelf. Nevertheless, differences in the expression of the secondary peaks are clearly visible.

During the field collection and analysis of the 1990-91 firn core, we found a visible pale brownish layer approximately 3 cm thick, near the bottom of the core at a depth of 27.8 meters. The layer was especially notable in the diffused lighting present in the trench at the drill site. This layer was analyzed in the normal sequence of core processing and was found to contain extremely high levels of nitrate and also to show conductivities that were very high (Figure 3b.). Using a petrographic microscope, we found that the ice contained particulates that included highly angular fragments of glassy material as well as some crystalline minerals (see Figure 4.). In this case, it is most likely that the high nitrate and high conductivity of the samples is related to the deposition of a layer of volcanic dust on the snow surface. Some of the nitrate contained in this layer could have been derived from chemical processes taking place in the eruption cloud and from electrostatic discharges which are known to accompany volcanic eruptions. Furthermore, if the dust were deposited on the snow surface during summer, it would have the effect of increasing absorption of solar radiation and would have greatly increased

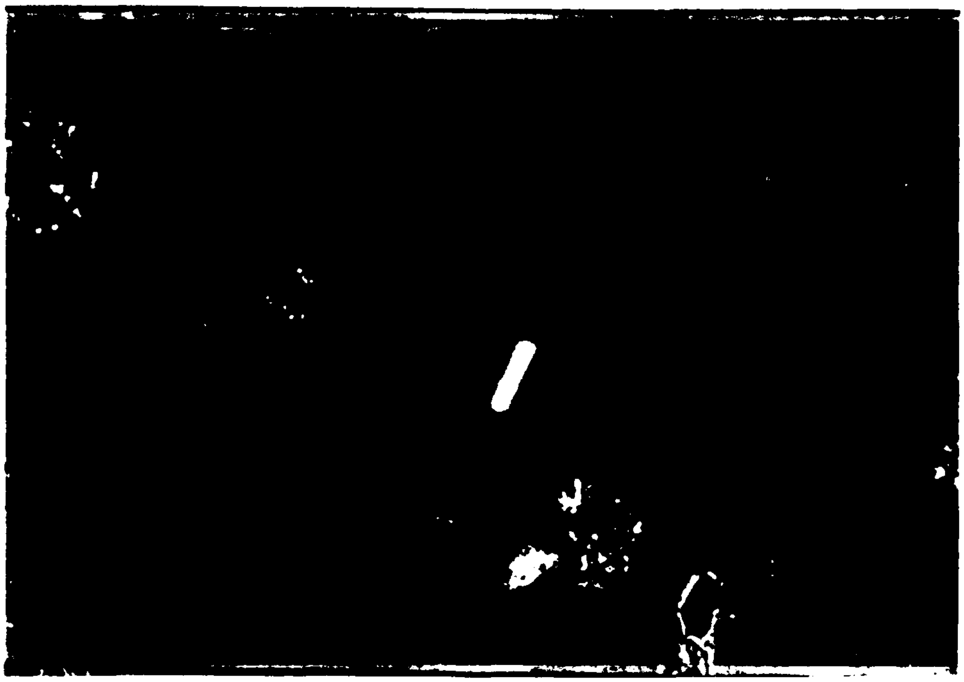

Figure 4. Photomicrograph of dust contained in ice samples from the dust layer shown in Figure 3. Magnification is X-200 in cross polarized light showing angular glassy aggregates and birefringent crystalline grains. Most probably derived from the volcano.

evaporation, causing concentration of soluble constituents in the surface layer. In any sequence of data obtained from ice cores, it is necessary to be able to distinguish between large primary nitrate peaks that are the result of giant solar flares and other large peaks that result from different phenomena like volcanic eruptions or major dust storms. In this case the sequence from the core collected in 1990-91 at Windless Bight provides an illustration of this type of problem (see Figure 3a.). Details of the 1991 data sequence will be discussed at the AGU Fall Meeting in San Francisco, 1991 (see Appendix C). This portion of the research was funded in part by grant NSF/DPP 8919190.

III. Apparatus Development for the 1992 Greenland Field Season

Recently new apparatus has been designed and built by us and the Center for Reasearch Inc., University of Kansas which will allow ultra-high resolution (~2 mm) measurement of nitrates and conductivity based on an automated continuous analytical system. This apparatus called the Polar Ice Core Analysis System (PICAS), has been constructed and is now under test in our laboratory. The equipment permits a melt stream from a heated probe that will melt vertically through the ice core to be pumped by a micropump through the well-tested Beckman Model 160 UV spectrophotometer analyzer cell. The effluent from this cell will then be passed in turn through the microcell of the Orion Model 160 conductivity apparatus as was done in the system that we used in Antarctica in 1990-91. Readout from both instruments is fed to a computer in the control unit where the data can be displayed for preliminary evaluation and then stored on disk. Construction of the melter probe has not been completed but a preliminary design has been tested. The micropump has been acquired and mounted on a variable speed electric motor and is now undergoing testing. The pump and all major components are stainless steel. The integrated unit will be field tested in Colorado this winter. The entire system weighs less than 100 lbs and is designed for field operation in polar climates.

After the field test and any redesign that may be necessary, this system will be used during the 1992 Greenland field season. Our team (Dreschhoff and Zeller) is scheduled to work at the Summit site (see map in Figure 5.) which is the deep drilling site (GISP II) for the United States and European glaciology research projects. The Polar Ice Coring Office (PICO) will drill a 100-120 meter deep core for us (see letter, Appendix D.) We expect to make all analyses of samples at the drill site. It would be impossible to complete analysis in the field in a single season without the PICAS system.

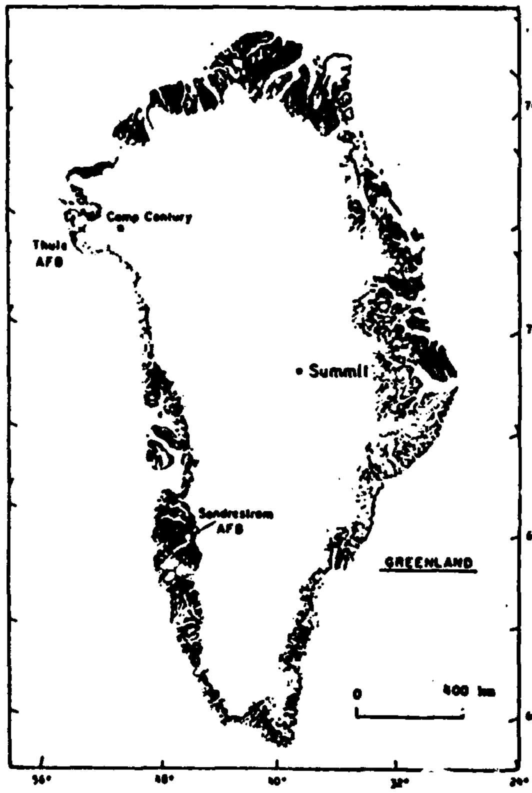

Figure 5. Map of Greenland showing the location of the field area at the Summit drill site. .

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V. Interactions and Activities

1.) Based on our experience in using a carbon dioxide laser for cutting ice cores, we have also designed a laser ice core drill which is described in detail in Appendix E.

2.) November 1990 - January 18, 1991. Antarctic field season and acquisition > 80 years of high resolution nitrate and conductivity data. We also comtacted Prof. Westphal in Antarctica where we discussed neutrino detection systems based on the use of polar ice as a Cerenkov medium. We had previously suggested this to Prof Halzen of the University of Wisconsin in 1988. (see acknowledgements in Appendix F.)

3.) May 1991 was spent at Zhengzhou University Physics Department as part of the World Bank - Provincial Universities Development Project.

4.) From June 1991 to September 1991 our laboratory was visited by Prof. Qin Dahe, Lanzhou Institute of Geology and Geocryology Chinese Academy of Sciences, China.

5.) We have contacted Dr. Julie Palais of NSF Division of Polar Programs to exchange data on the dust layer found near the battom of our firn core.

6.) Dr. Joan Feynman visited the Physics Department at the University of Kansas in August 1991 and subsequently spent one day visiting our lab. A statistical comparison between our nitrate profiles was discussed.

Preprint
Submitted to JGR Sept. 1991

DISTRIBUTION OF NITRATE CONTENT IN THE SURFACE SNOW OF THE ANTARCTIC ICE SHEET ALONG THE ROUTE OF THE 1990 INTERNATIONAL TRANS-ANTARCTICA EXPEDITION

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Abstract

Previous work showed that nitrate measured at very high resolution (1.5 cm) in snow depositional sequences in Antarctica could be corrected with short term phenomena such as solar proton events (Dreschhoff and Zeller, 1990). It was clear that deposition of the ionization products in the snow is strongly dependent upon precipitation and atmospheric conditions during and immediately after the event. Information about the geographic distribution of the nitrate fallout over Antarctica was limited to only a few sites however. A unique opportunity to examine this aspect of the nitrate distribution and to test more fully the hypothesis that atmospheric ionization from solar charged particles is responsible for a significant portion of nitrate was presented to us by a set of surface snow samples collected by the International Trans-Antarctica Expedition foot traverse. The set of 95 samples of the upper 25 cm was collected by one of us, (Qin), at roughly equal distances along the 5736 kilometer route from 27th July, 1989 to 3rd March, 1990. Samples are distributed along a track from 65°05'S, 59°35'W, through 90°S, to 66°33'S, 95°39'E, which represents geomagnetic latitudes 50°S,West longitude, to 77°S, East longitude. The profiles of nitrate concentration and flux along the route were plotted and indicate that (especially at the higher elevation of the polar plateau) the distribution is, at least in part, controlled by the interaction between the magnetosphere and the flux occurs in areas where electron precipitation is known to be unusually high (Sheldon et al., 1988)

Introduction

The nitrate content in the snow and ice at several sites in Antarctica have been reported by previous authors (Paker et al., 1978; Zeller and Parker, 1981; Delmas, 1986; Legrand, 1987; Dreschhoff and Zeller, 1990; Mayewski and Legrand, 1990). These previous studies focused not only on the nitrate concentration, and the distribution and temporal variations, but also on the sources about which the authors have different opinions. However, these glaciological investigations, including the nitrates, in the Antarctic ice sheet are limited to a few sites, such as South Pole, Vostok Station, Dome C, Ross Ice Shelf, etc. No systematic investigation of the nitrate content has been made in the surface snow of the major geographic zones of the Antarctic ice sheet, especially in a single austral field season, although major differences in concentration at sites were reported as being related to their location with reference to the auroral zone (Zeller an Parker, 1981). This paper presents the results of the nitrate analysis of surface snow samples collected along the 1990 International Trans-Antarctica Expedition (1990 ITAE) route from about 50°S magnetic latitude, West longitude, through 90° S to about 77° S magnetic latitude, East longitude.

Sampling and analytical procedures

The 1990 ITAE completed the crossing of the Antarctic continent along the longest route, starting from Seal Nunataks (65°05'S, 59°35'W) on 27th July, 1989, and arriving at Mirnyy Station (66°33'S, 95°39'E) on 3rd March, 1990. The traverse covered the northern part of the Larsen Ice Shelf and the southern part of the Antarctic Peninsula, Palmer Land, Ellsworth Mts., South Pole (90°00'S), Vostok (78°28'S, 106°48'E) and Komsomolskaya Stations (74°05'S, 97°27'E) (Fig. 1). The total distance of 5736 km was completed within 220 days. 95 samples of 25 cm depth of surface snow were collected in polyethylene bottles along this route at equidistant points. The bottles were new and were washed three times using Milli-Q-Water to clean each bottle and permit us to maintain accuracy in the ppb range for ionic measurement of the snow samples. The washed bottles were packed in clean bags in the clean room and were opened only during sampling for a short time. Specific steps were adopted to keep the samples clean during sampling, for example, to face the windward direction, to wear gloves and to clean the surface of the profile of the snow pit, so that contamination was avoided.

All of the samples were kept frozen until processed. The nitrate content of the samples was analyzed at the Space Technology Center, University of Kansas, USA, by a Beckman 160 UV Selectable Wavelength Spectrophotometer. Absorbance is determined with an analytical precision of $\leq$ 2%, and when calibrated against standards, indicates that the mean concentration for the 95 snow samples collected on the ITAE was 22.2 ppb $\pm$1 ppb ($NO_3^- - N$).

Before the processing of the samples in Kansas, these 95 samples had been analyzed for 12 ions by ion chromatography in the Laboratory de Glaciologie et Geophysique de L'Environnement, France. All of the samples have been melted in the clean room in France for 3-6 hours, then immediately refrozen and kept in cold storage for shipment to the United States. For the ionic analyses, all samples were handled in a manner that avoided any contamination, so that the accuracy of the next analyses would not be compromised (Qin Dahe et al., in preparation). The excellent agreement between the analytical results in France and those at the University of Kansas suggest strongly that these precautions were successful.

Results

Table 1 presents the results of the nitrate analysis of the samples, as well as the detailed basic data of the sampling. In Table 1 the sampling date, the position and the distance from Station 1 (Seal Nunataks) are recorded. The elevation value is obtained from the large contour map of Antarctica edited by Drewry (1982), according to the records of station position. The mean annual accumulation rate has been collected from previous publications, and its source is indicated in Table 1, and the annual nitrate flux is the product of the measured nitrate concentration and the snow accumulation rate. The data on the accumulation rate is available only for 61 stations, for which most of the data possess high accuracy, especially in the segment from Station 47 to 85 (Table 1). Assuming the mean density of the 25 cm surface snow is 0.3 g/cm^3 (Qin Dahe and Ren Jiawen, 1991; Lipekove, 1980), the 25 cm snow would cover roughly 1-3 average year's snow falls in most of the 61 sampling stations. Taking into account the complex nature of snow accumulation, it can be argued that the 25 cm surface snow was deposited in the recent past. That means the nitrate flux in the 25 cm snow represents present nitrate deposition, in recent snow accumulation.

Fig. 2 and Fig. 3 show the distributions of the nitrate concentration at 95 stations and of nitrate flux at 61 stations in recent snow along the 5736 km route across Antarctica.

Discussion

The distribution of the nitrate concentration in 25 cm surface snow along the route of the 1990 ITAE in Fig. 2 shows that the concentration in the inland segment is higher than that in the coastal segments. To be precise, the nitrate concentration in the surface snow of the Antarctic Plateau, from Station 47 to Station 84, where the elevation is between 2600 m and 3560 m a.s.l., is generally higher than that at the other stations, where the sampling sites are limited to the Larsen Ice Shelf, Antarctic Peninsula or to localities within a 600 km distance from the coast lines. Fig. 2 also shows that the highest concentration values are not in the center of the Plateau, but in the segments on the route of 2 to 3 degrees of latitude on both sides of the South Pole. However, the nitrate concentration in the 25 cm surface snow alone can not describe quatitatively the overall characteristics of nitrate distribution in Antarctica. In Fig 3., the relationship between the nitrate flux and the route distance is plotted and it provides an obvious illustration of the nitrate deposition along the route. In Fig. 3, there are only 61 nitrate flux values, because it is impossible to collect the complete accumulation data of all stations. This figure shows that the nitrate flux value is higher along the coast or in the near-coast regions, and generally lower in the inland region. However, with the exception of three stations located outside of the inland segment, the highest nitrate flux value is at Station 48 (88°38'S, 96°26'W). In Fig. 3, we also can observe that the lower nitrate flux values are concentrated in the center of the Antarctic Plateau segment, mainly from Station 60 (85°33'S, 105°40'E) to Station 80 (74°44'S, 98°41'E). In this segment the nitrate concentrations shown in Fig. 2 are high and show strong variations from station to station.

To account for the above-mentioned distribution we must consider the mechanisms by which the nitrate is produced and transported to Antarctic surface snow. In the prior studies, Zeller and Parker (1981) had considered a total of 14 possible mechanisms for the origin of nitrate in Antarctic snow and ice. Clausen and Langway (1989) also indicated that the nitrate impurity observed in the Antarctic snow has a multiple source origin. From the earlier analyses, the nitrate sources

could include continental, atmospheric, stratospheric contributions, and anthropogenic activity effects, consisting of biomass burning, soils and dust, oxidation of NH_3, photochemical processes, lighting, and several effects of cosmic related factors. But Prospero and Savoie (1989) analyzed the observed data of nitrate collected from a Pacific island network, and found the nitrate concentration in the air of the Northern Pacific to be three times greater than that of the Southern Pacific. They found in the Northern Pacific, that the higher nitrate concentration is correlated with Asian dust transport, and by contrast, suggested that the nitrate concentration in the Southern Pacific region is related to oceanic 'background' sources. Petit et al. (1991) analyzed the excess deuterium in recent Antarctic snow and concluded that the moisture of the precipitation in the center of the Antarctic ice sheet is derived from the warmer ocean of the southern lower-mid latitude. In the coastal region of the Antarctic ice sheet, the moisture of the precipitation is derived from the adjacent oceans. From these observations, it follows that biomass burning, continental and anthropogenic sources, can basically be neglected as substantial contributors to nitrate in Antarctic snow and ice.

Because of the remoteness of Antarctica from other continents, upper atmospheric sources make an important contribution to the nitrate contained in Antarctic snow and ice. This interpretation furnishes a partial explanation for the nitrate flux distribution. Our investigation shows that the nitrate flux in the inland segment is lower than that in the coastal or near-coastal segments of Antarctica, especially at the edge of the ice sheet (Fig. 3). Accumulation rates are very low in the interior of Antarctica, and the moisture, as well as some of the nitrate, derives from the lower latitude Southern Ocean where the 'background" of nitrate is actually quite low (Prospero and Savoie, 1989). But in the coastal region, the snow accumulation is very high, with greater nitrate flux from the local air masses. Even so, the nitrate concentration remains quite low (Table 1 and Fig. 2). In the coastal region, there is a large extent of exposed soils and rocks in moraines, nunataks and mountains. Claridge and Campbell (1968) showed that soil in the ice-free areas is frequently very high in nitrate. It appears likely that the atmospheric contribution determines the basic nitrate flux distribution in the surface snow of the Antarctic ice sheet especially in the inland region as well as in the coastal region. The area of the immediate coast is probably influenced strongly by the locally exposed soils which contribute additional nitrate.

However, our data have revealed some unexpected results shown in Fig. 2 and Fig. 3. Specifically, the highest nitrate concentrations are located on both sides of 2-3 degrees of latitude from the South Pole (Fig. 2). The highest nitrate flux in the inland segment is also located in this area (Fig. 3). These samples were collected during the Antarctic midsummer period, 1989 (Table 1). Moreover, in Fig. 3 high nitrate flux also appeared around 78°S latitude in the Ellsworth Mountain region. These samples were collected in late October, 1989. It appears that in these segments, we have to be concerned about three component contributions to the spatial distribution of nitrate concentration and flux across the continent. First, a background component is subject to general circulation and storm system transport over the Antarctic Ice Sheet. Second, superimposed anomalies in nitrate flux can result from ionization in the auroral zone and thirdly in the lower ionosphere (≤ D-region) caused mostly by highly penetrating electron precipitation. Several authors have discussed the changes in the chemical composition of the upper and middle atmosphere due to ionization by charged particles (Swider, 1977; Jackman et al., 1980; Thone, 1980; Rusch et al., 1981; Solomon et al., 1981; Garcia et al., 1984)

If the nitrate anomalies can be accounted for by atmospheric ionization products, the nitrate fallout at any specific collection site must be related, in part, to the location of the site relative to the geomagnetic latitude (see Fig. 4). Specifically, an area about 2 to 3 degrees latitude from the geographic South Pole (geomagnetic latitude 75 degrees and Station 51 in the ITAE traverse) should be expected to exhibit auroral zone contributions when compared to ITAE stations between South Pole and Vostok. Lanzerotti et al. (1984) and Rosenberg et al. (1987) pointed out that the conjugation of the magnetic field lines and spatial extent of open or closed magnetic field lines mostly above 70 degrees geomagnetic latitude are a strong function of geomagnetic local time and the variation in flux of charged particles. We would expect that any contributions of nitrate as an upper atmospheric ionization product should be at a minimum in the very high geomagnetic positions along the ITAE route. This coincides with results from the all-sky images taken at South Pole Station (Mende and Rairden, 1987). In addition, auroral absorption or ionospheric absorption of radio waves by electrons that penetrate deeply into the lower ionosphere has been found to exhibit a maximum at about 66 degrees magnetic latitude (Krishnaswamy and Rosenberg, 1985).

These types of results by riometer measurements coincide with rocket observations and model calculations on the coupling of relativistic magnetospheric electrons to the middle atmosphere (Baker et al., 1987). In addition, there is a strong longitudinal variation in the penetrating electron precipitation in the Southern Hemisphere (Sheldon et al., 1987). In fact, Sheldon et al. (1988) estimated that in certain areas of Antarctica, the rate of electron precipitation and therefore rate of ionization that could cause changes in the chemical composition of the atmosphere would be particularly high because of its association with the magnetic South Atlantic Anomaly. ITAE station 27 (Table 1 and Fig. 4) would clearly fall into this zone.

Some of our nitrate values from three sations along the ITAE can be compared with previous results reported in the literature. Herron (1982), Legrand and Delmas (1986) and Legrand et al. (1984) calculated the nitrate (in ppb) fluxes at Siple (some hundred years in the Holocene), South Pole (1959-1969) and Vostok (Holocene) to be 11, 7.6 and 1.3 $kg/km^2 \cdot a(NO_3^-)$, respectively. Our results at the same sites are 1.8, 1.5 and 0.6 $kg/km^2 \cdot a(NO_3^- - N)$, respectively. The difference between the fluxes at these sites may be due to the fact the nitrate data reported here represent samples from the most recent time period of about two years, i.e. 1988-1989. However the general characteristic of these two groups of results shows that the highest value is at Siple, the lowest at Vostok, with South Pole showing an intermediate flux. This distribution of nitrate fluxes does not contradict the apparent relationship between the collection sites and geomagnetic latitudes, including the effects of the position of the auroral zone. For example, due to the fact that Vostok Station is closest to 90 degrees geomagnetic latitude, contributions from the auroral zone should be comparatively low throughout all seasons. (Mende and Rairden, 1987).

A significant difference between nitrate data reported in the literature and the results of our measurements is to be found in the flux ratio between Siple and Vostok Stations. Data from previous studies indicates a ratio of 8.5 whereas our measurements show only 3. Without more samples and data relating to the exact nature of the snow sequence sampled by the previous workers at these collection sites, these differences are difficult to evaluate and they may actually represent a change in nitrate deposition that has taken place in the recent past. We know that deposition from polar stratospheric clouds containing nitric acid is possible (McElroy

et al., 1988; Wofsy et al., 1990) and that there is a depletion of stratospheric ozone over Antarctica (Fiocco et al., 1989; Mayewski and Legrand, 1990). We also know that there is an interannual variability in the intensity, position and location of the polar vortex over the Antarctic Ice Sheet (Bowman, 1986). In short, the differences in the nitrate flux ratios between Siple and Vostok may be the result of significant changes in ozone depletion as well as solar variability over Antarctica over the past few years.

Conclusions

In this paper the nitrate concentration and the flux in the surface snow of Antarctica along the route of the ITAE, 5736 km, has been presented. The distributional characteristics of the nitrate has been defined by our results for this profile accross the remote polar continent which is separated from other land masses by the bulk of the Southern Ocean. Three mechanisms seem to be important in determining the spatial distribution of nitrate in the top 25 cm of the surface snow in the regions traversed by the ITAE. These three mechanisms are related to the Southern Ocean, auroral activity as well as anomalous electron precipitation and the processes related to ozone depletion. Although short-lived effects from solar proton events undoubtably are present they could only be identified as anomalies in high-resolution samples of snow sequences extending over at least one year (Dreschhoff and Zeller, 1990).

The local coastal ocean and the remote southern lower-mid latitude ocean provide a partial origin for the nitrate transported by atmospheric circulations and deposited in the Antarctic snow and ice in the coastal and inland regions. The variation in the precipitation rate in Antarctica causes the basic distribution of nitrate flux, the higher flux in the coastal region and the lower in the inland. For this reason, the Southern Ocean furnishes the largest contribution to the nitrate budget in Antarctic snow and ice. In some segments of our sampling route the nitrate flux is strikingly increased in zones of auroral activity and enhanced electron precipitation. These phenomena do not seem to be simple coincidence. Upper atmosphere physics studies provide extensive evidence to support this interpretation.

While we believe that we have distinct evidence of a magnetospheric effect on the nitrate fallout along the ITAE traverse, the investigation presented here is based upon a small number of samples (95) collected over a short time (July 1989 to March

1990) during a period of extreme variability in charged particle emission from the sun. Clearly, to substantiate this conclusion, future investigations will have to pay special attention to magnetospheric effects as well as spatial and temporal location of the collection sites.

Acknowledgement

This project was supported by The National Committee for Antarctic Research of China,The National Committee of Science and Technology of China and National Natural Science Foundation of China. Partial support was provided by US National Science Foundation grant DPP 8919190 and the US Air Force constract AFOSR 88-0065. The authors would like to thank the members of ITAE, and the staffs of the offices of ITAE and SAE for their help and logistic works. We also thank Dr. P. A. Mayewski and Mr. C. P. Wake of University of New Hampshire, USA, and Dr. J. R. Petit and Dr. R. J. Delmas of IGGE, France, for their support.

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Figure Captions

Fig. 1. Antarctic map showing the route of the 1990 International Trans-Antarctica Expedition (ITAE) and the sampling stations.

Fig. 2. Nitrate concentrations in 25 cm depth of surface snow on the Antarctic Ice Sheet and elevation along the route of the ITAE.

Fig. 3. Nitrate flux in 25 cm surface snow and elevation along the route of the ITAE.

Fig. 4. Map showing the ITAE traverse relative to the geomagnetic latitudes and nominal average position of the auroral zone (shaded area) for geomagnetic local noon at the South Pole (adapted from Weller et al., 1987).

Table 1

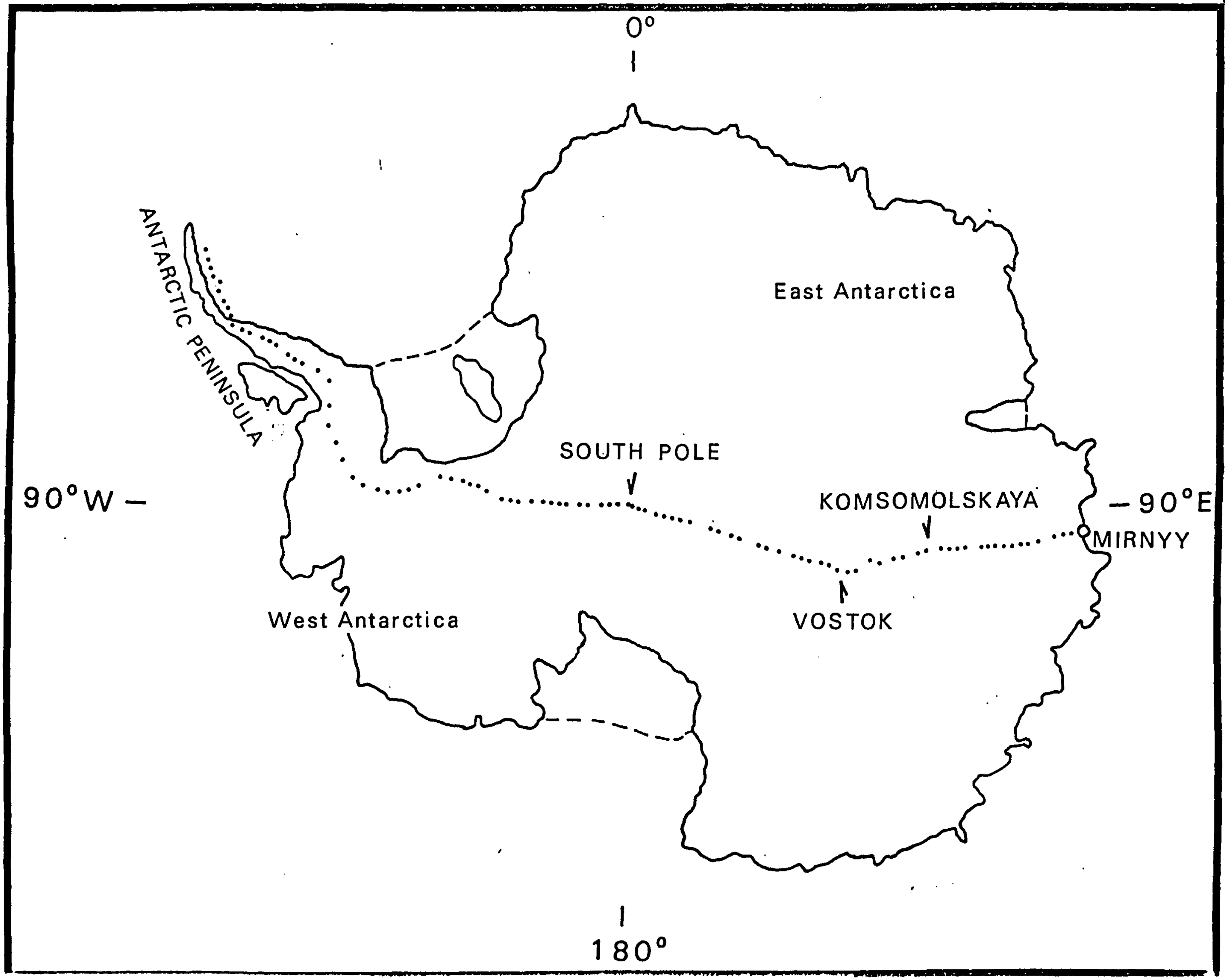
Table 1. The results of nitrate concentration of 95 samples and the interrelated data. The references for accumulation rate are as follows: (1). Kotlyakov et al., 1977; (2). Giovinetto and Bull, 1987; (3). Peel and Clausen, 1982; (4). Hamilton et al., 1971; (5). Shimizu, 1964; (6). Taylor, 1965; (7). Jouzel et al., 1983; (8). Jouzel et al., 1990; (9). Lipenkov, 1980.

Table-1 (NO3)

	station no	sampling date(d/m/y)	position	distance(km)	elevation(m)	NO3(ppb-N)	accu. (kg/m2.a)	accu. source	flux(kg/km2.a)	station name
1	1	27/07/1989	65°05'S, 59°39'W	0	0	3.7				
2	2	01/08/1989	65°35'S, 61°10'W	63	50	5.6				
3	3	03/08/1989	65°50'S, 61°57'W	100	90	10.1				
4	4	10/08/1989	66°20'S, 62°36'W	153	70	10.1				
5	5	13/08/1989	66°54'S, 63°20'W	249	50	5.0				
6	6	15/08/1989	67°20'S, 64°07'W	303	50	15.1	600	1, 2	9.1	
7	7	18/08/1989	67°47'S, 64°42'W	360	80	8.4				
8	8	23/08/1989	68°25'S, 65°15'W	418	200	14.7				
9	9	27/08/1989	68°43'S, 65°26'W	459	1200	18.6				
10	10	31/08/1989	69°10'S, 65°18'W	497	1700	17.7				
11	11	05/09/1989	69°41'S, 65°13'W	570	1600	3.7	164	3	0.6	Weyerhaeuser Gl.
12	12	09/09/1989	70°25'S, 64°44'W	607	1950	16.2	164	3	2.7	
13	13	14/09/1989	70°58'S, 64°41'W	676	2000	11.4				
14	14	15/09/1989	71°17'S, 64°43'W	708	1650	20.7				
15	15	17/09/1989	71°56'S, 65°18'W	782	1250	10.8				
16	16	18/09/1989	72°14'S, 65°29'W	814	1250	11.7				
17	17	19/09/1989	72°33'S, 65°55'W	851	1000	7.8				
18	18	23/09/1989	73°14'S, 66°48'W	929	1200	12.5				
19	19	06/10/1989	74°05'S, 69°57'W	1107	1450	6.7	338	4	2.3	
20	20	09/10/1989	74°46'S, 72°46'W	1217	1520	7.1	251	4	1.8	
21	21	11/10/1989	74°51'S, 75°45'W	1302	700	10.6	265	4	2.8	
22	22	15/10/1989	75°26'S, 78°29'W	1400	450	10.1	228	4	2.4	Eights
23	23	18/10/1989	75°47'S, 81°40'W	1503	750	8.4				
24	24	24/10/1989	76°25'S, 85°10'W	1569	1050	7.3	344	5	2.5	
25	25	26/10/1989	76°56'S, 86°15'W	1633	1100	10.4				
26	26	28/10/1989	77°39'S, 87°07'W	1703	1500	10.4				
27	27	30/10/1989	78°12'S, 87°39'W	1761	1650	14.7	400	1, 2	5.9	
28	28	01/11/1989	78°49'S, 87°14'W	1838	2050	7.8	300	1, 2	2.3	
29	29	02/11/1989	79°10'S, 86°51'W	1872	1800	16.4				
30	30	04/11/1989	79°45'S, 85°08'W	1949	1680	12.5	200	1, 2	2.5	
31	31	09/11/1989	80°18'S, 81°21'W	2092	700	16.2				Patriod Hills
32	32	11/10/1989	80°45'S, 81°15'W	2116	900	10.8				
33	33	14/11/1989	81°12'S, 82°00'W	2148	900	5.2				
34	34	16/11/1989	81°48'S, 82°50'W	2224	1050	8.8				
35	35	17/11/1989	81°55'S, 83°20'W	2262	1150	9.5				
36	36	19/11/1989	82°41'S, 84°00'W	2329	1250	16.6				
37	37	20/11/1989	83°05'S, 84°45'W	2369	1320	15.5				
38	38	22/11/1989	83°47'S, 87°25'W	2446	1480	16.2	150	1, 2	2.4	
39	39	23/11/1989	84°12'S, 88°05'W	2490	1550	15.3				
40	40	24/11/1989	84°35'S, 88°55'W	2534	1650	23.5				
41	41	26/11/1989	85°11'S, 88°58'W	2622	1730	15.3				
42	42	29/11/1989	85°53'S, 88°10'W	2709	1850	14.7				Thiel Mts.
43	43	30/11/1989	86°12'S, 88°25'W	2746	2000	18.6	100	1, 2	1.9	
44	44	02/12/1989	86°34'S, 88°57'W	2828	2050	19.6				
45	45	03/12/1989	86°54'S, 90°19'W	2875	2200	25.0				
46	46	05/12/1989	87°36'S, 91°06'W	2946	2380	22.2				
47	47	06/12/1989	87°57'S, 91°55'W	2984	2550	49.3	82	6	4.0	
48	48	08/12/1989	88°38'S, 92°26'W	3062	2650	55.5	80		4.4	
49	49	09/12/1989	89°00'S, 92°58'W	3100	2750	29.8	76	6	2.3	
50	50	10/12/1989	89°22'S, 91°39'W	3141	2850	32.6	81		2.6	

Table-1 (NO3)

	station no	sampling date(d/m/y)	position		distance(km)	elevation(m)	NO3(ppb-N)	accu. (kg/m2.a)	accu. source	flux(kg/km2.a)	station name
51	51	13/12/1989	90°00'S		3207	2880	17.1	85	7	1.5	South Pole
52	52	16/12/1989	89°53'S,	114°22'E	3215	2880	36.3	81		2.9	
53	53	17/12/1989	89°32'S,	108°18'E	3255	2900	46.9	74		3.5	
54	54	18/12/1989	89°11'S,	105°35'E	3297	2950	41.0	68		2.8	
55	55	20/12/1989	88°26'S,	104°27'E	3377	3050	53.3	56		3.0	
56	56	21/12/1989	88°03'S,	104°35'E	3416	3070	36.9	50	1, 2	1.8	
57	57	22/12/1989	87°42'S,	104°39'E	3456	3130	48.4	49		2.4	
58	58	23/12/1989	87°20'S,	104°25'E	3496	3150	49.0	48		2.4	
59	59	25/12/1989	86°57'S,	104°57'E	3578	3150	56.2	46		2.6	
60	60	29/12/1989	85°33'S,	105°40'E	3696	3160	38.9	43		1.7	
61	61	30/12/1989	85°13'S,	105°49'E	3733	3180	18.4	42		0.8	
62	62	01/01/1990	84°28'S,	106°10'E	3813	3210	35.4	40		1.4	
63	63	02/01/1990	84°07'S,	106°17'E	3853	3230	32.6	39		1.3	
64	64	03/01/1990	83°44'S,	106°24'E	3895	3230	39.3	38		1.5	
65	65	05/01/1990	83°00'S,	106°12'E	3896	3260	28.7	36		1.0	
66	66	06/01/1990	82°40'S,	106°19'E	4014	3280	24.0	35		0.8	
67	67	09/01/1990	81°50'S,	106°28'E	4092	3310	32.2	33		1.1	
68	68	11/01/1990	81°05'S,	106°26'E	4175	3410	50.1	31		1.6	
69	69	12/01/1990	80°42'S,	106°12'E	4217	3400	36.1	30		1.1	
70	70	13/01/1990	80°17'S,	106°04'E	4264	3420	27.0	29		0.8	
71	71	14/01/1990	79°42'S,	106°04'E	4304	3430	21.4	27		0.6	
72	72	16/01/1990	79°08'S,	106°08'E	4396	3430	22.2	25		0.6	
73	73	17/01/1990	78°46'S,	106°41'E	4428	3480	25.6	23	8	0.6	Vostok Station
74	74	22/01/1990	78°07'S,	105°47'E	4475	3500	34.8	23		0.8	
75	75	23/01/1990	77°43'S,	104°47'E	4525	3510	46.4	30	9	1.4	
76	76	25/01/1990	77°00'S,	102°55'E	4611	3550	45.1	33	9	1.5	
77	77	26/01/1990	76°36'S,	102°00'E	4655	3550	29.6	36	9	1.1	
78	78	28/01/1990	75°54'S,	100°31'E	4733	3560	26.6	37	9	1.0	
79	79	29/01/1990	75°33'S,	100°13'E	4772	3550	35.0	31	9	1.1	
80	80	31/01/1990	74°44'S,	98°41'E	4844	3550	26.1	37	9	1.0	
81	81	01/02/1990	74°21'S,	98°00'E	4886	3500	32.8	66	9	2.2	Komsomolskaya
82	82	04/02/1990	73°41'S,	97°26'E	4958	3490	38.2	61	9	2.3	
83	83	05/02/1990	73°18'S,	97°09'E	5002	3430	22.5	71	9	1.6	
84	84	06/02/1990	72°51'S,	96°59'E	5052	3380	40.2	78	9	3.1	
85	85	07/02/1990	72°28'S,	96°45'E	5059	3320	13.8	91	9	1.3	Vostok-1
86	86	09/02/1990	71°42'S,	96°17'E	5179	3180	21.6	123	9	2.7	
87	87	10/02/1990	71°20'S,	96°01'E	5221	3093	13.7	123	9	1.7	
88	88	11/02/1990	70°57'S,	95°54'E	5262	2980	15.8	129	9	2.0	
89	89	12/02/1990	70°33'S,	95°43'E	5307	2870	14.5	126	9	1.8	
90	90	14/02/1990	70°11'S,	95°35'E	5351	2820	16.0	160	9	2.6	
91	91	18/02/1990	69°36'S,	95°07'E	5441	2650	17.9	112	9	2.0	
92	92	21/02/1990	68°51'S,	94°37'E	5505	2400	13.8	106	9	1.5	
93	93	23/02/1990	68°05'S,	93°50'E	5591	2080	10.6	189	9	2.0	
94	94	24/02/1990	67°42'S,	93°39'E	5634	1850	17.5	403	9	7.1	
95	95	25/02/1990	67°21'S,	93°26'E	5673	1480	8.4	490	9	4.1	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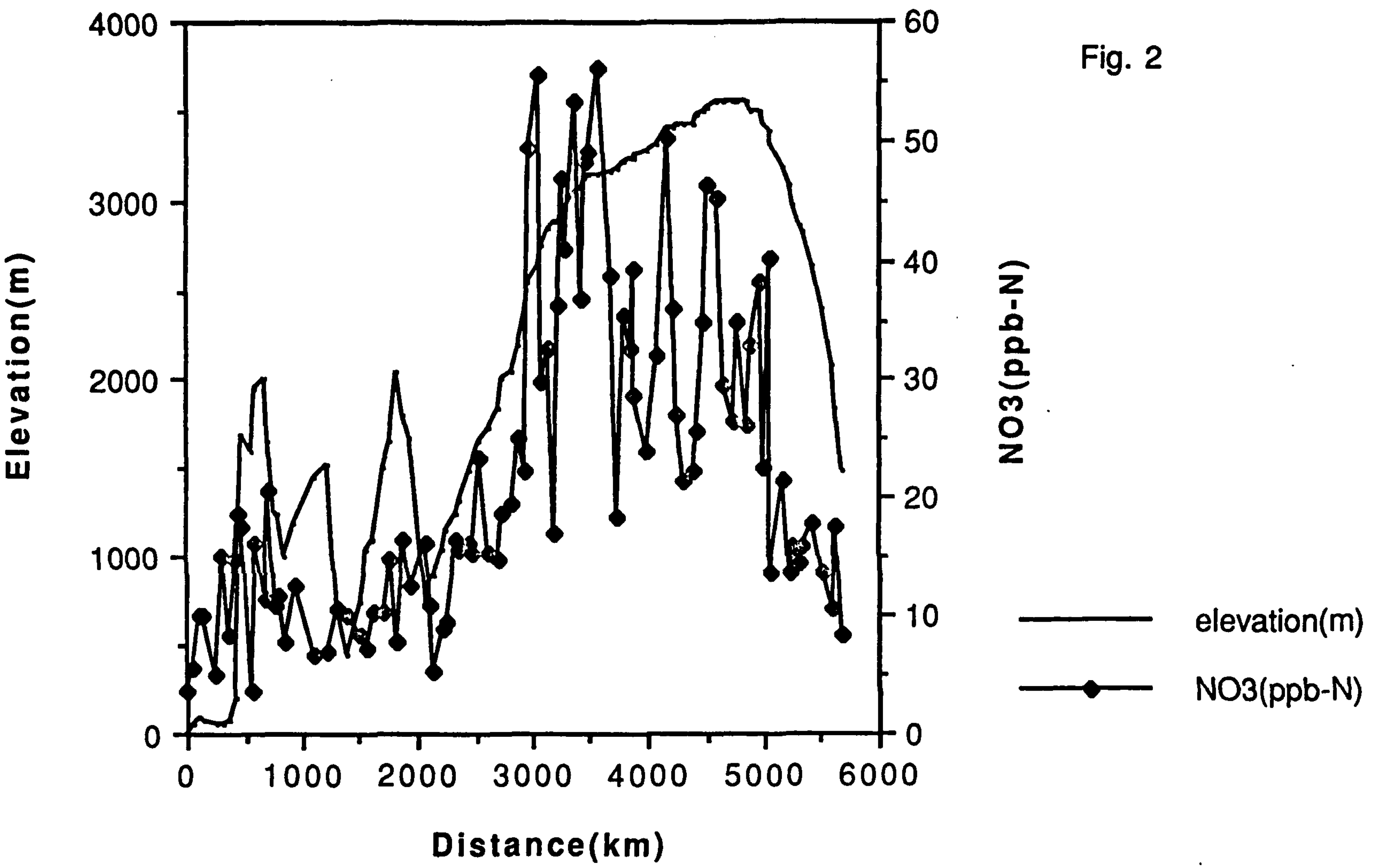
MIRNYY
West Antarctica
VOSTOK
180°

Fig. 2


Elevation(m)
NO3(ppb-N)
Distance(km)
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3000
4000
5000
6000

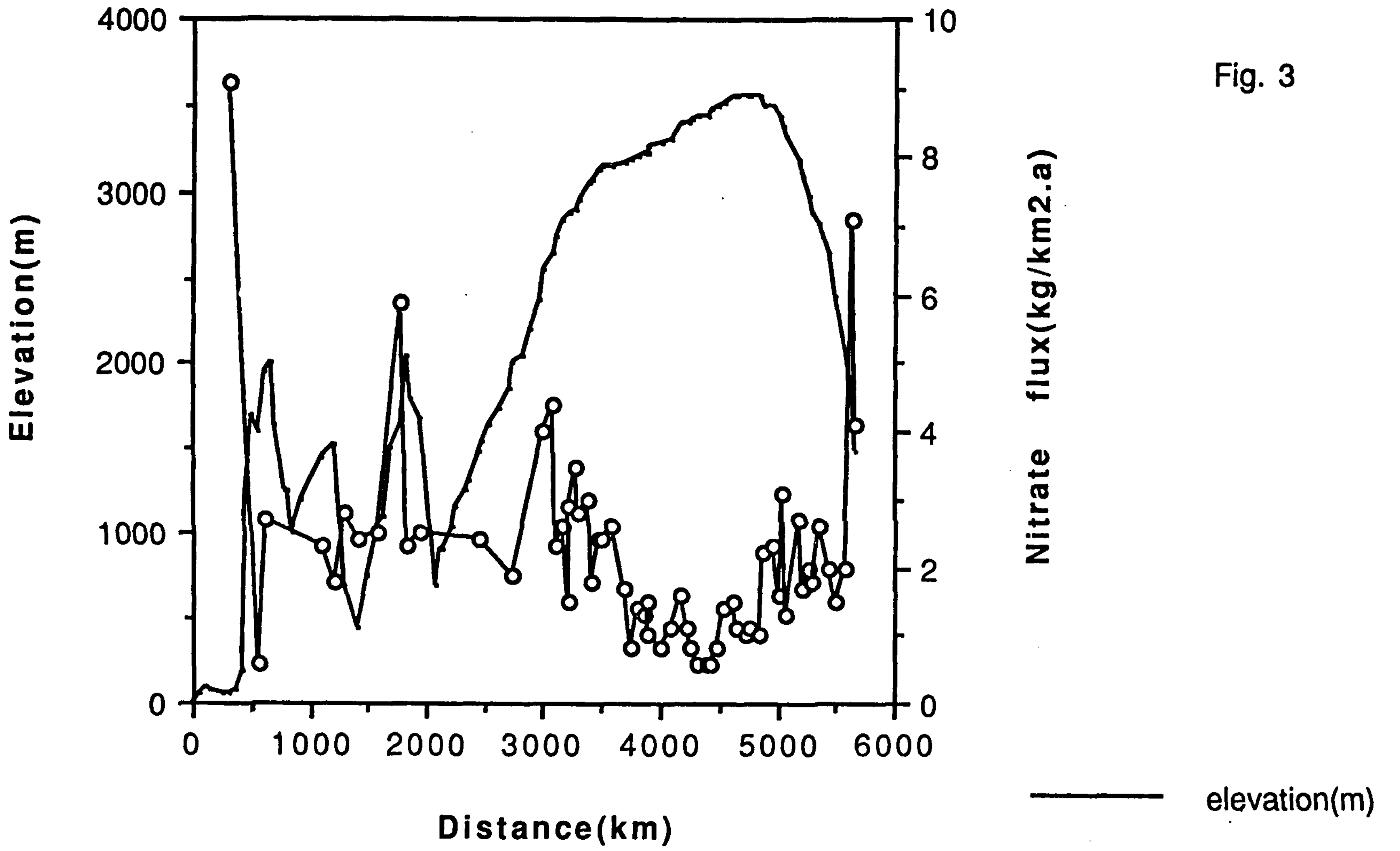
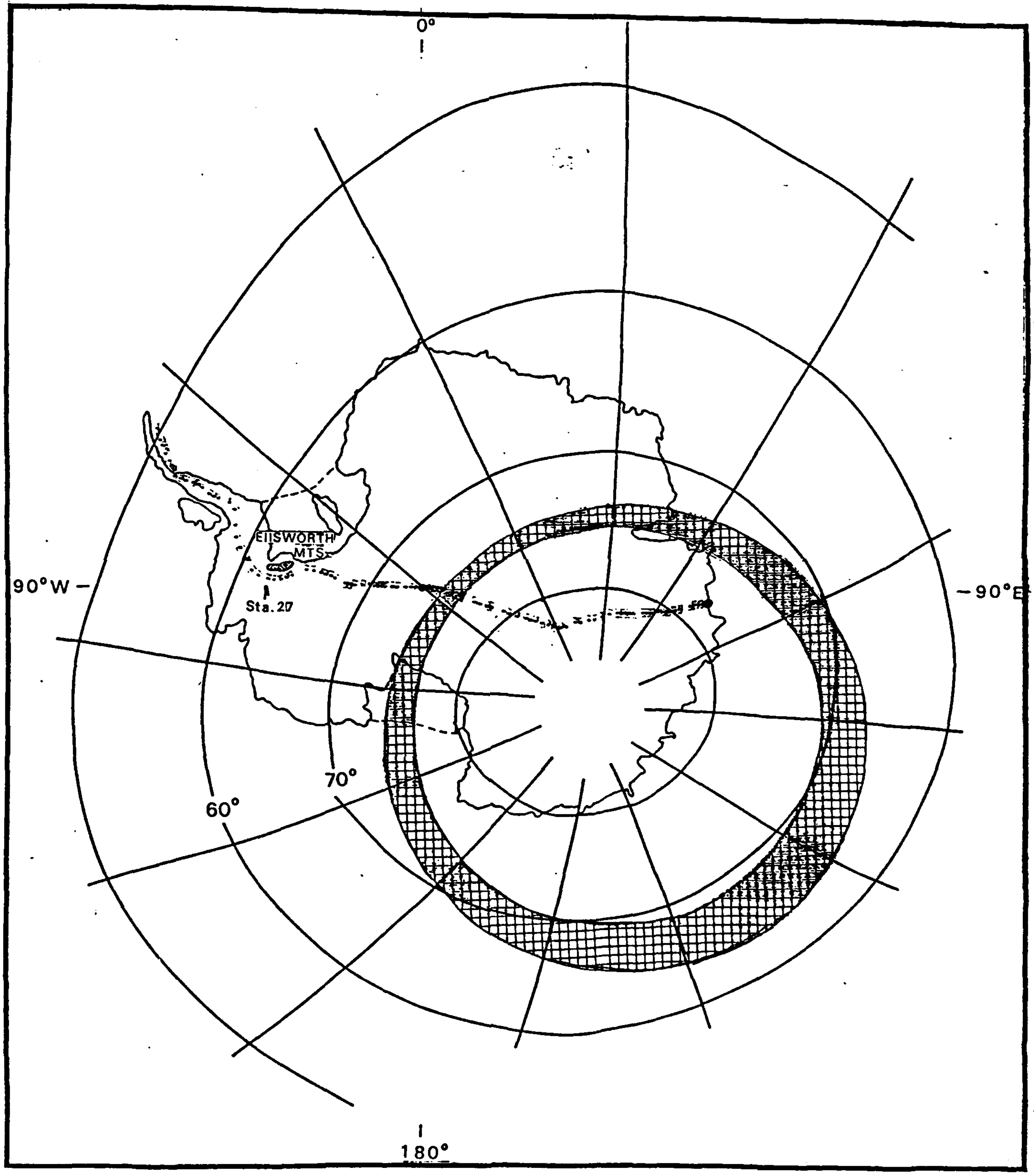

Elevation(m)
4000
3000
2000
1000
0
0
1000
2000
3000
4000
5000
6000
Distance(km)
10
8
6
4
2
0
Nitrate flux(kg/km2.a)
elevation(m)
flux(kg/km2.a)

Fig. 3


0°
90°W
90°E
ELLSWORTH
MTS
Sta.27
70°
60°
180°

Electron Precipitation and Nitrate Deposition Along the Route of the 1990 International Trans-Antarctic Expedition

Qin Dahe (Lanzhou Inst. of Glaciology and Geocryology, Chinese Academy of Sciences, Lanzhou, Gansu 730000, China)
E. J. Zeller and G. Dreschhoff (Both at: Space Technology Center, 2291 Irving Hill Drv. Lawrence, KS 66045)

A set of surface snow samples collected by the International Trans-Antarctica foot traverse constitutes a unique opportunity to test the hypothesis that ionization from solar charged particles is responsible for a significant portion of the nitrate in Antarctic snow. Ninety five samples of the upper 25 cm were collected by one of us (Qin) at roughly equal distances along the 5736 km route from 27 July, 1989 to 3 March, 1990. These samples are distributed along a track from 65°05'S, 59°35'W longitude, through 90°S, to 66°33'S, 95°39'E, which represents geomagnetic latitudes ~50°S, W to ~77°S, E longitude. Nitrate concentrations and flux along the route are plotted relative to distance and the altitude curve is superimposed on the plots. Altitude clearly affects precipitation rates and influences the fallout of trace compounds to the surface. In addition, the results show that the nitrate flux across the Antarctic continent is, at least in part, controlled by the interaction between the magnetosphere and the upper atmosphere. The results also show that the highest nitrate flux occurs in an area where electron precipitation is known to be unusually high.

1. 1991 Fall Meeting

2. 000901157

3. (a) G. Dreschhoff
Space Tech Center
2291 Irving Hill Dr.
Lawrence, KS 66045
(b) 913-864-4517

4. U

5. (a) U03 Paleoastrophysics and natural variation of cosmogenic isotopes
(b) 2475 Polar ionosphere
2716 Energetic particles, precip.

7. 0%

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9. C

Ionization Products from Solar Flares Retained in Antarctic Snow

E. J. Zeller and G. Dreschhoff (Both at: Space Technology Center, 2291 Irving Hill Drv. Lawrence, KS 66045)
J. Feynman (Jet Propulsion Laboratory, 4800 Oak Grove Drv. Pasadena, CA 91109)

Over a seven year period, high resolution chemical analysis for nitrate ion in firn sequences from the Windless Bight area of the Ross Ice Shelf in Antarctica have been made. These time series have been assembled and confirm that nitrate concentrations in polar ice and snow can be used to provide reliable signals of past solar flare activity. It has been found that major solar proton events produce strong anomalies that are tracable from nitrate sequences separated by as much as 10 kilometers. On the other hand, anomalies that are related to individual snow storms and depositional conditions occur only in a single time series and appear to be determined by the specific conditions at the site. These data present a basis for quantitiative evaluation of the nitrate anomalies versus the proton flux from the associated SPE's. A companion paper (Qin, Zeller and Dreschhoff) shows that electron precipitation associated with the auroral zone may be responsible for the spatial distribution of nitrate fallout over the Antarctic continent and plays a major role in determining the nitrate background over broad areas.

1. 1991 Fall Meeting
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NATIONAL SCIENCE FOUNDATION
1800 G STREET, N.W.
WASHINGTON, D.C. 20550

Dr. Gisela Dreschhoff
Radiation Physics Lab
University of Kansas Space
Technology Center
2291 Irving Hill Drive
Lawrence, Kansas 66045-2969

Dear Gisela, September, 13 1991

Thanks for reminding me that I still had not responded to your letter of July 8, 1991 regarding your request for assistance from NSF for transport and shallow drilling at Summit, Greenland during the 1992 field season. Please contact PICO and ask them to come up with a budget for the support you require (separating the drilling, camp support (if any) and transportation). As I understand it, the Air Force will pick up your transportation costs directly by making arrangements with the 109th. I suppose the flights on which you and your cargo are transported to GISP2 will cost PICO/NSF less than a similar flight with just PICO/NSF cargo and personnel. Eventually we can discuss with the Division of Grants and Contracts (DGC) the exact mechanism by which you will transfer funds from your Air Force grant to DPP/NSF for the drilling support you get from PICO.

In the near future someone from NSF will be sending you a questionaire to fill out so that we may include your program in our application to the Danish Commision for permission to work in Greenland. Chuck Myers in DPP usually handles those questionaires. If you do not receive one by late Fall let me know so that I can get him to send you one. Finally, as soon as next summer's schedule becomes clear we can discuss when you might go up to Summit. I suspect the month of August will be the best for us but we can discuss that at a later time.

Let me know if you have anymore questions about this matter. Good luck with your work and please say hello to Ed for me.

Sincerely,

Julie M. Palais

Julie M. Palais
Polar Glaciology

cc: Dr. J. Kelley, PICO
Dr. H. Zimmerman, DPP/NSF
Dr. Ted DeLaca, DPP/NSF
Dr. Dennis Peacock, DPP/NSF

Submitted to Antarctic Journal, July 1991

Development of Laser Ice Cutting Apparatus

Edward Zeller, Gisela Dreschhoff, Claude M. Laird

Radiation Physics Laboratory,
Space Technology Center
University of Kansas,
Lawrence, Kansas, 66045

During the 1990/91 field season at Windless Bight near Ross Island, our team introduced the use of a 25 watt continuous infrared carbon dioxide laser as a field device to cut individual firn cores for sample preparation. The test was successful and permited this device to be employed on a routine basis in field operations. Carbon dioxide laser cutting systems have the advantage that the beam is emitted at an infrared wavelength that is absorbed in a very short distance in ice. We were able to demonstrate conclusively that the laser beam can cut cleanly and rapidly through both firn and ice and that it can be manipulated efficiently with standard optical systems.

Subsequently, upon our return to the laboratory at the University of Kansas, we tested the system on a 4 inch diameter ice core from the Greenland ice sheet taken at a depth of about 170 meters (Koci, personal communication). The core was supplied to us by P. Grootes. In this case, cutting was

performed in an open freezer with the initial temperature of approximately -20 C using about 15 watts total power output. The cutting was performed without optical condensers using the beam directly from the laser. We were able to slice off a 2 inch segment of the core without shattering or fragmentation of any kind. The cut was about 2 mm wide and could have been reduced to half that width with an optical system. A video tape taken in the laboratory at the time of the cutting experiment was prepared and sent to NSF/DPP and PICO.

In the process of completing this experiment, we determined that it would be possible to develop an optical system that would permit the beam to be rotated in a circular path that could be used for cutting deep ice cores. With minor modifications this system could be used in fluid filled holes as well as in open holes.

The fact that the laser beam cuts entirely by melting and exerts no torque on the ice at the cutting surface, greatly reduces the potential for fracturing and breakage of the core during drilling. Even more important, the fact that the beam can be deflected at 90 degrees to the drilling direction means that the ice core can be cut off at the bottom of the hole by the beam. This has the effect of greatly reducing stress on the core at the time it is lifted free of the bottom of the hole. Finally, chemical contamination cannot be introduced by

the laser beam and the infrared wavelengths used for drilling are too long to cause significant radiolytic breakdown keeping chemical alterations of all types at an absolute minimum.

In construction of a prototype, the rotating mass of the optical system and the thin-walled core barrel will be so low that only the lightest of anti-torque systems must be used. The entire drill assembly including the laser, optics, core barrel and scavenger pump system can be expected to weigh less than 200 lbs and can be supported on a light weight cable that must include electrical conductors for the 28 volt power supply to the laser. Power requirements are modest. Electrical power to the completed system can be supplied by a 3,000 watt generating facility and should be fully adequate for all operations including drilling and hoisting of the drill and core barrel assembly.

The simplest drill design is shown in Figure A. In this design, the carbon dioxide laser is mounted vertically in the bore hole and a rotating head containing deflecting mirrors is attached so that the laser beam can be directed down against the ice and turned in a circle by a small, low power, direct current motor. In principle, it is possible to design the drill so that the radius of the core is adjustable but we propose to build a system with a fixed core diameter (most probably 4 inches).

In any vertical ice drilling operation involving an infrared laser beam it is necessary to remove the water from the annulus cut by the beam. This will be done by a small scavenger pump that will pick up the water at the point where it is being produced and transfer it to a holding tank at the top of the core barrel. It will be necessary to empty this holding tank each time the core barrel is withdrawn from the hole.

Figure B, is a design for an optical system that would permit switching the laser beam path from the position used for drilling (through beam window 1) to the position used for cutting the core lose from the bottom of the hole (through beam window 2). This would be accomplished by activating the beam selector at the center of the optical bridge. This portion of the drill assembly would be located at the top of the core barrel.

Figure C, shows the design of the core barrel. It would be constructed of two thin-wall steel tubes arranged concentrically with the space between the tubes being used as the location of the optical wave guide fiber and the vacuum line to the scavenger pump. In the proposed prototype drill, we will construct a core barrel to accomodate a 1.5 meter ice core segment to reduce weight and make preliminary testing easier. In a scaled up version, the core barrel could be extended to 3 or 4 meters.

Using the laser that we already have and some of the equipment from our laboratory, we expect to produce a proof-of-concept prototype. Because of the ruggedness and high efficiency of carbon dioxide lasers, we believe that this system could be upgraded to produce a workable drill for use in polar regions that would greatly reduce the logistic requirements for transport and power.

Acknowledgements

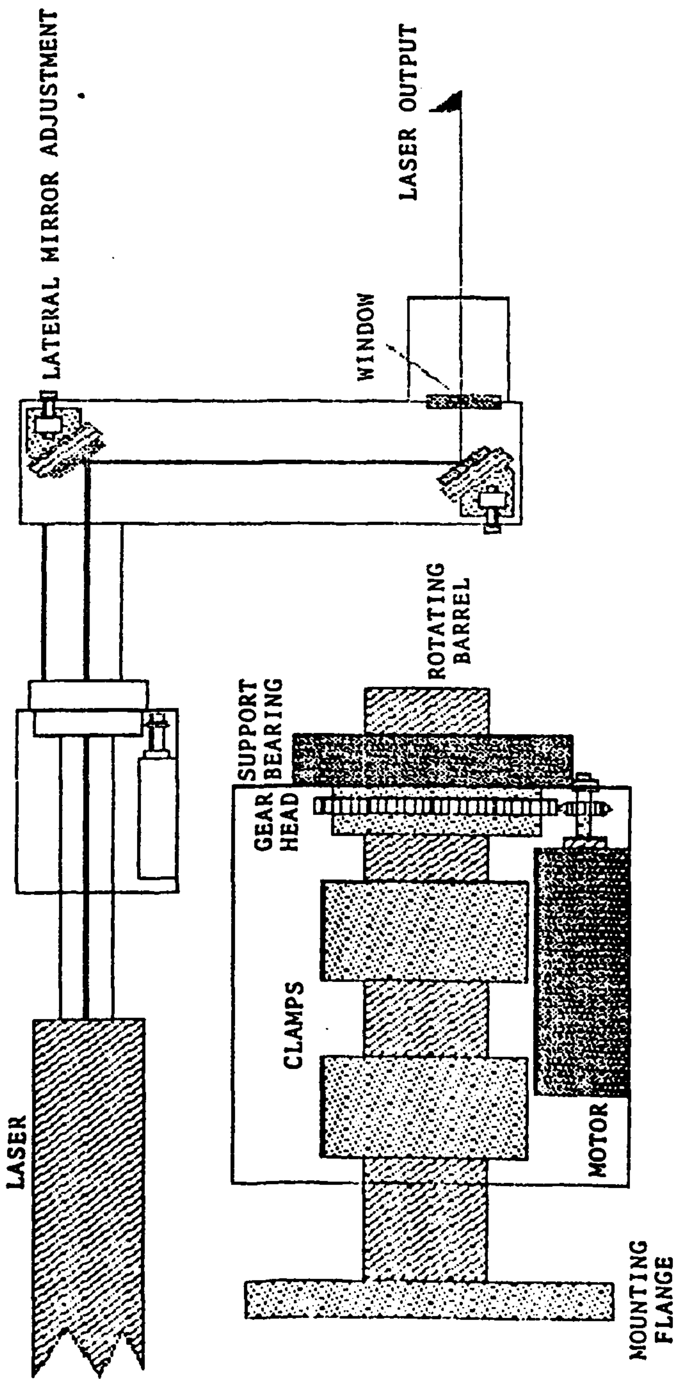
This work was funded in part by NSF Grant DPP-8919190 and Air Force contract AFOSR-88-0065. We wish to acknowledge the help of Wesley Ellison of the Center for Research Inc. of the University of Kansas in design and construction of our laser system.

FIGURE CAPTIONS

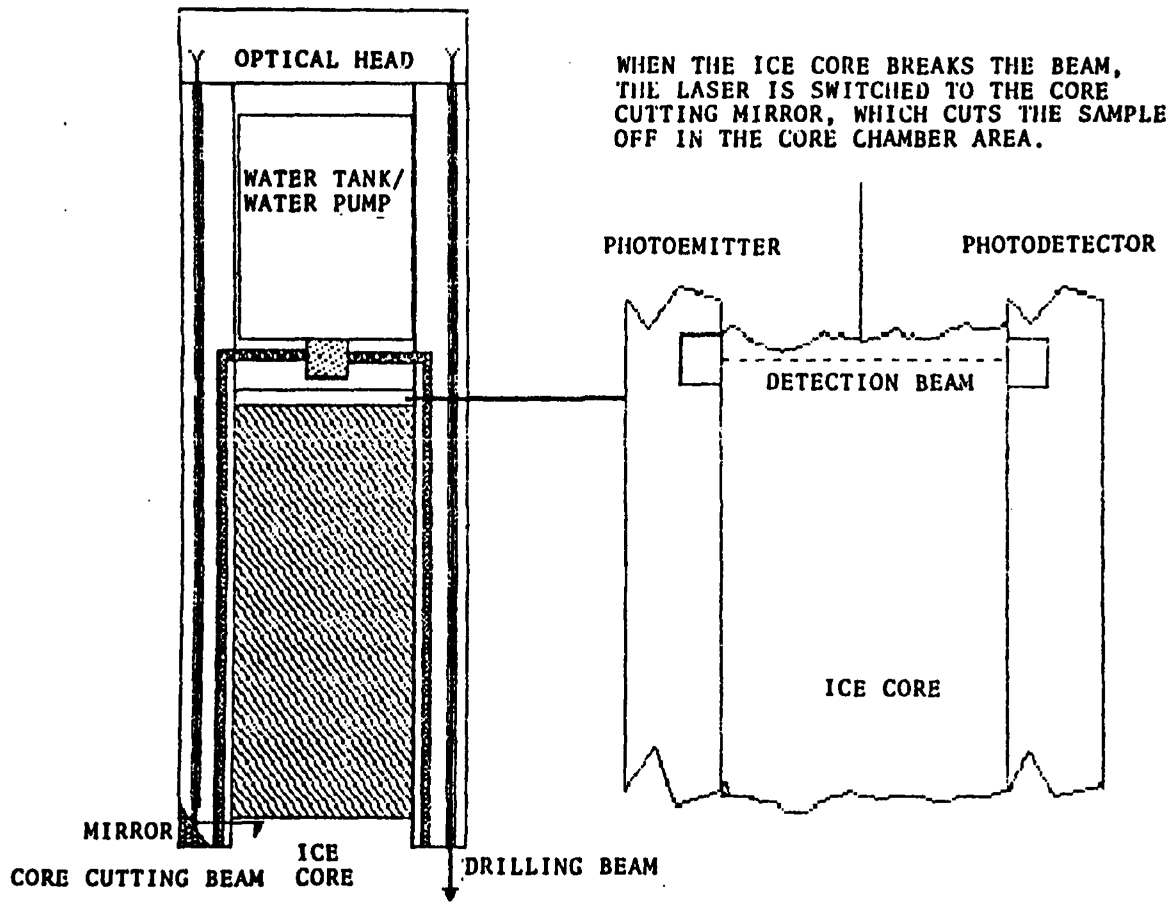
Figure A. The drill assembly consists mainly of an infra-red CO_2 laser, optics, core barrel and scavenger pump system, and is expected to weigh less than 200 lbs.

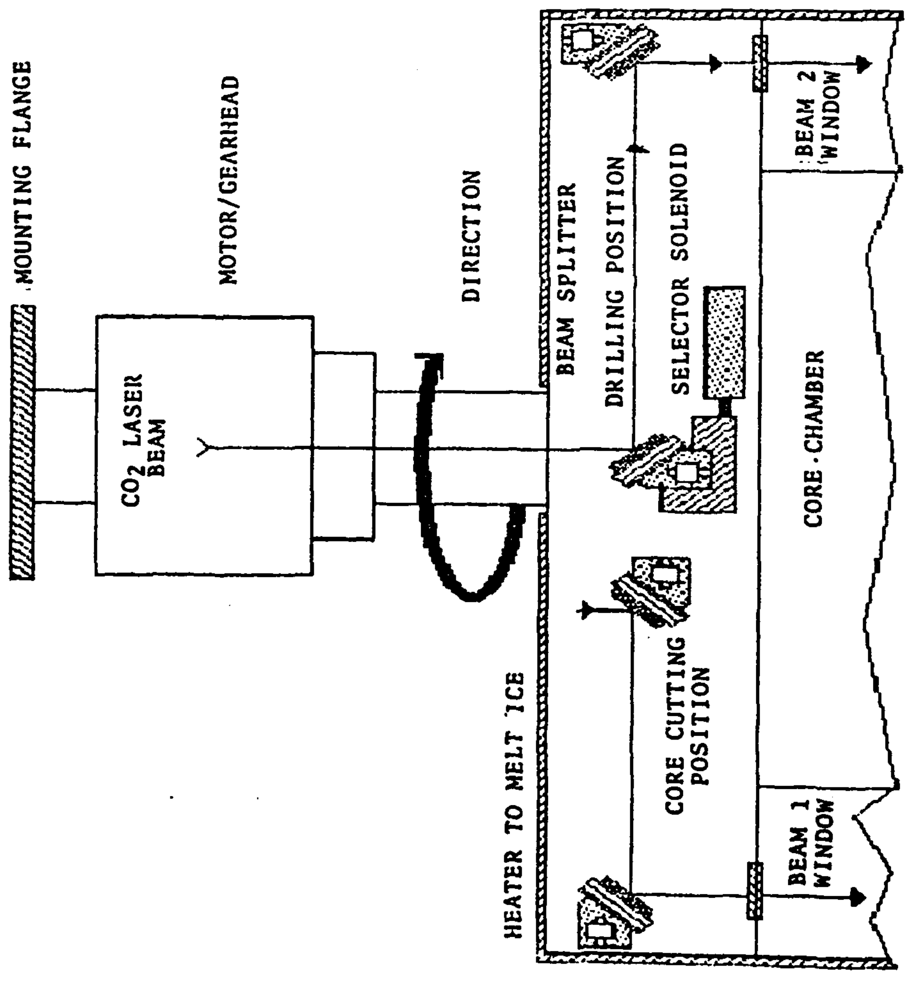
Figure B. Design of the optical system that would permit switching the laser beam path from the position for drilling to the position for cutting the core loose at the bottom of the drill hole.

Figure C. The design of the core barrel includes the construction of two thin-walled concentric steel tubes. The space between the tubes will be used as the location of the wave guide fiber and the vacuum line to the scavenger pump.



LATERAL MIRROR ADJUSTMENT
LASER OUTPUT
WINDOW
ROTATING BARREL
SUPPORT BEARING
GEAR HEAD
CLAMPS
LASER
MOTOR
MOUNTING FLANGE


OPTICAL HEAD
WATER TANK/
WATER PUMP
MIRROR
CORE CUTTING BEAM
ICE
CORE
DRILLING BEAM
WHEN THE ICE CORE BREAKS THE BEAM,
THE LASER IS SWITCHED TO THE CORE
CUTTING MIRROR, WHICH CUTS THE SAMPLE
OFF IN THE CORE CHAMBER AREA.
PHOTOEMITTER
PHOTODETECTOR
DETECTION BEAM
ICE CORE



MOUNTING FLANGE
CO_2 LASER BEAM
MOTOR/GEARHEAD
DIRECTION
BEAM SPLITTER
DRILLING POSITION
SELECTOR SOLENOID
CORE CHAMBER
BEAM 2 WINDOW
HEATER TO MELT ICE
CORE CUTTING POSITION
BEAM 1 WINDOW

(as they predicted, given the complex profiles); this can be explained by a precessional variation of unresolved components of the He II profile in their analysis.

The corresponding masses of the compact object and the normal star can be easily derived from equation 1: we find $M_{*} \approx 3.2 \pm 0.4 M_{\odot}$ and $M_{x} \approx 0.8 \pm 0.1 M_{\odot}$. The above estimates for F and q, taken at face value, imply therefore that the compact object is a neutron star rather than a black hole. Given the high quality of our spectra, we are fairly confident of the value of K. A somewhat higher mass ratio could be inferred considering, as suggested in ref. 16, a moderate flattening of the secondary or a wind-type mass flow that would obscure the X-rays for a small fraction of the eclipse.

The quality of our data also allows us to study the position and strength of the line peaks. For this purpose we chose seven spectra with clear double-peaked structure. Note that the peaks are rather weak (Fig. 1) so that the line always shows a strong central component with the orbital variation described above. Sine fits to the position of the two underlying gaussians and to the intensity ratio of the two peaks are given in Table 1. We find (Fig. 2) that the red peak is stronger when the line is redshifted and the blue peak is stronger when the line is blueshifted. The position of the blue peak seems to vary much less than the position of the red peak.

Unequal orbital modulation of the two peaks seems to support the idea of two unrelated emission regions, one approaching us and the other receding at several hundred kilometres per second. But the He II line at 4,686 Å is produced in a hot environment, so one of the peaks is likely to be emitted in the binary system region which should have small systemic velocity.

In cataclysmic variables as well as X-ray binaries, the He II emission comes from the vicinity of the compact object or, more precisely, from the corona surrounding the accretion disk. We believe that this is the case in SS433 as well. The peak separation of ~7.8 Å corresponds to the keplerian radius of $\leq 3 \times 10^{11}$ cm for a neutron star that is smaller than the radius of its Roche lobe.

The intensity ratio of the two peaks is such that the part of the accretion disk facing the normal star is always dimmer. This rules out the illumination from the normal star as a possible source of different peak strengths. Similarly, the eclipse of the accretion disk is far too short to cause this effect. Another possibility would be the contribution by emission from the hot spot; it is unlikely, however, that the hot spot lies on the part of the accretion disk facing away from the secondary. Finally, the emission of the He II line from the part of the corona facing the donor star might be partly absorbed by a strong wind from the hot-spot region. The existence of such outflow has been inferred from the analysis of photometric light curves[17] and X-ray observations[18]. The rotation of the disc together with such periodic obscuration can explain both the strength and the separation modulation of the peaks. On the other hand, the high scatter of the redshifted line modulation and the large separation of the peaks on the spectrum obtained on 18 October indicate additional nonperiodic effects. Double peaks have also been observed in the Paschen stationary lines[19]. The splitting is smaller than observed in the He II line. This is consistent with the picture of lower-excitation lines being emitted in the outer parts of the disk (which are cooler and rotate more slowly) or in the wind from it.

In conclusion, the lower value of K measured here, together with the estimate of the mass ratio from X-ray observations of the primary eclipse, lead us to believe that the compact object in SS433 has a lower mass than previously thought. The double-peak structure observed in the He II line at 4,686 Å is here interpreted as due to emission from the corona of the accretion disk. □

Received 3 June; accepted 19 July 1991.

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ACKNOWLEDGEMENTS. We would like to thank A. Čadež and R. Falomo for reading the manuscript. The observations on which this paper is based were obtained during the commissioning of EMMI. We are grateful to the EMMI project team for the excellent performance of the instrument.

Observation of muons using the polar ice cap as a Cerenkov detector

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DETECTION of the small flux of extraterrestrial neutrinos expected at energies above 1 TeV, and identification of their astrophysical point sources, will require neutrino telescopes with effective areas measured in square kilometres—much larger than detectors now existing[1–3]. Such a device can be built only by using some naturally occurring detecting medium of enormous extent: deep Antarctic ice is a strong candidate. A neutrino telescope could be constructed by drilling holes in the ice with hot water into which photomultiplier tubes could be placed to a depth of 1 km. Neutrinos would be recorded, as in underground neutrino detectors using water as the medium, by the observation of Cerenkov radiation from secondary muons. We have begun the AMANDA (Antarctic Muon and Neutrino Detector Array) project to test this idea, and here we describe a pilot experiment using photomultiplier tubes placed into Arctic ice in Greenland. Cerenkov radiation from muons was detected, and a comparison of count rate with the expected muon flux indicates that the ice is very transparent, with an absorption length greater than 18 m. Our results suggest that a full-scale Antarctic ice detector is technically quite feasible.

Neutrinos would be detected by the standard technique of observing the Cerenkov light emitted by upward-moving muons, produced by neutrinos interacting in or below the detector. At these high energies, the direction of the muon produced is within 1° of the direction of the parent neutrino, so the observation of astrophysical neutrino sources is possible in principle. Such a detector at the South Pole would have many advantages: (1) unlike existing and some proposed detectors, there would be no physical limit to its size and structure, and it could be gradually expanded (holes could be added year after year); (2) the ice would form a mechanical structure for the instrument, enabling all active electronics other than photomultiplier tubes (PMTs) to be placed directly above at the surface, putting most

of the electronics within reach for adjustment and maintenance; (3) the lack of background light sources (for example, natural radioactivity) deep in the ice combined with low ambient temperatures imply that PMT noise rates should be very low; (4) location at the South Pole would have unique astronomical advantages—for instance, the observation of sources at constant zenith angle and the ability to observe neutrinos from a Northern Hemisphere source simultaneously with the observation of ultra-high-energy gamma rays from the same source by Northern Hemisphere air-shower arrays. For this technique to work, the ice must be very transparent (peak optical absorption length > several metres). In this initial study, conducted at the Greenland Ice Sheet Project II site (72° N, 38° W.) during 13-16 August 1990, muon rate measurements were made to assess the optical clarity of polar ice.

A string of three Thorn EMI model 9870 PMTs, each 12 cm in diameter with a hemispherical window, was lowered down a 15-cm-diameter borehole to a depth of −217 m, ~100 m below the firn (packed snow) layer (Fig. 1). Operating close to single photoelectron sensitivity, the PMTs had noise rates between 10 and 20 kHz, higher than expected, and due to surface light leaking down the borehole. The event trigger required that all three PMTs produce a digital pulse within 30 ns of each other; the observed coincidence rate was 1.8 Hz. By inserting additional time delays to destroy the real coincidence window, the purely random coincidence rate was directly measured to be 0.2 Hz, well below the 1.8-Hz coincidence rate. From previous muon flux measurements and calculations[4], the vertical muon flux at depth (217 m = 180 m water-equivalent) is 1 muon $m^{-2}\,s^{-1}\,sr^{-1}$. The corrected event rate of 1.6 Hz, together with the expected vertical flux, indicates that each PMT was sensitive to muons arriving within a radius of ~1 m (Fig. 2). Thus, the experiment shows that a PMT placed at a depth of 200 m in polar ice is capable of acting as a detector with an effective area >3 m^2. In addition, the Monte Carlo studies described next indicate that if all PMTs were operated at the single photoelectron level (not possible in Greenland because of the high noise rates), the effective area of the string would increase from ~3 to ~6 m^2.

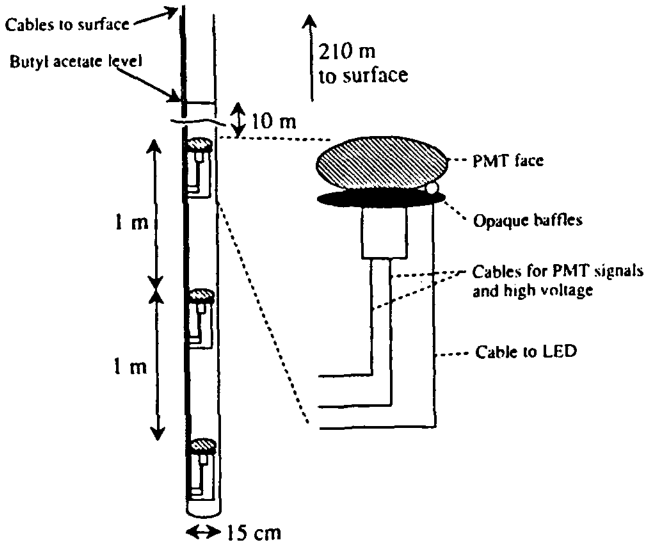

FIG. 1 PMT string used in Greenland. The three PMTs were arranged vertically, with 1-m separation between PMTs. Each PMT had a hemispherical window, and faced upwards. The hole was filled with butyl acetate, an organic liquid chosen for its low freezing point and clarity, to a depth of 11 m, for good optical contact between the PMTs and the borehole walls. The PMTs were equipped with voltage divider chains housed in pressure vessels, and high voltage was provided from the surface directly. The PMT analog output was routed through a coaxial cable (RG 180) directly to a receiver on the surface that was specifically designed by Phillips Electronics to compensate for the attenuation and dispersion introduced by the cable. Using this receiver, only a small attenuation (<25%) was observed in the amplitude of the PMT output, and the characteristic ~10 ns rise time of the PMT signal was preserved. The output signals from the receiver were routed into amplifiers, coincidence circuitry and CAMAC readout electronics. Discriminator thresholds were set as low as possible (30 mV), resulting in a sensitivity to signals greater than 1 photoelectron equivalent (p.e.) for the top PMT, 1 p.e. for the middle PMT and 2 p.e. for the bottom PMT.

Ice at this depth has a large concentration of air bubbles; the ice cores taken from this depth are milky and translucent. Davis[5] has calculated the non-isotropic intensity distribution of light scattered by air bubbles in water, which is a good approximation to the case of air bubbles in ice. We have done Monte Carlo calculations of photon propagation in the ice, using the Davis results. In the limit where $N \geqslant 20$, a numerical fit to the radial distributions generated by the Monte Carlo gives $d = \lambda(1+3\sqrt{N})$, where d is the mean radial distance reached after N scatters, and λ is the mean free path for light scattering and $\lambda = 1/(\sigma\rho)$, where σ is the bubble cross-sectional area and ρ is the number density of bubbles. Analysis of cores taken previously from this depth in Greenland (A. J. Gow, personal communication) indicates that there are 200 bubbles cm^{-3} of mean radius 0.017 cm, giving $\lambda \sim 5.5$ cm. (For our particular experiment, $N \approx 40$, using $d = 1$ m from the rate analysis given previously and $\lambda = 5.5$ cm). These results have been incorporated into a Monte Carlo calculation to predict muon rates and pulse-height distributions for each PMT. Using the known muon flux and angular distribution, Cerenkov photons were generated from the muon paths and propagated through the bubbly ice. The program included the quantum efficiency and collection efficiency of the PMTs as measured by the manufacturer and the variation of PMT effective area with the zenith angle of an incoming photon, measured as part of the calibration of this type of PMT for the Irvine-Michigan-Brookhaven proton decay experiment[6]. The absorption length of the light in the clear ice between bubbles was scaled as a fraction of measured laboratory values[7] (it should be pointed out that laboratory measurements of absorption include some scattering effects, and may therefore underestimate the true absorption length). Good agreement between the predicted and observed pulse-height distributions is achieved only if the peak optical absorption length of the *in situ* polar ice is greater than ~18 m, or 75% of the absorption length measured for pure laboratory ice (Fig. 3). Systematic uncertainties in the Monte Carlo calculation (for example, an

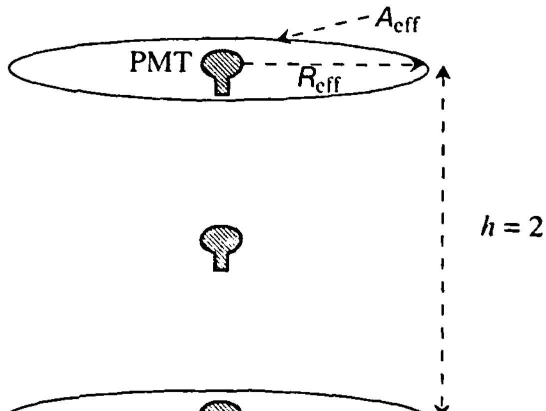

FIG. 2 The PMT string shown as a cylindrical detector, for calculation from the muon rate of the effective area of a PMT. The geometrical aperture of the instrument, in m^2 sr, times the muon flux (1.0 $m^{-2}\,sr^{-1}\,s^{-1}$) yields the muon rate (1.6 Hz), so the aperture is 1.6 m^2 sr. Visualizing the PMT string as shown, the geometrical aperture is[11]

$$\frac{\pi^2}{2}\left(2R_{eff}^2 + h^2 - \sqrt{4R_{eff}^2 h^2 + h^4}\right)$$

This yields $R_{eff} = 1.0$ m, or $A_{eff} = 3.1$ m^2.

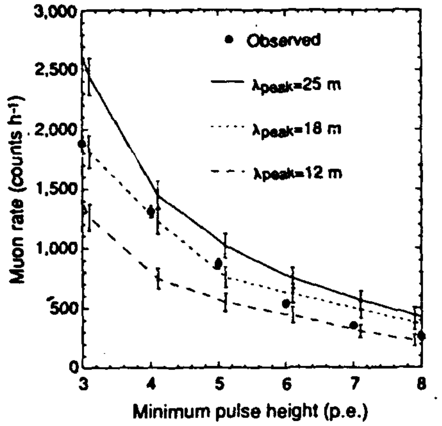

FIG. 3 Integral muon rate as a function of minimum pulse height (in p.e.) required of all three PMTs. Filled circles show experimental results, solid line shows Monte Carlo predictions if the Greenland ice has peak optical absorption length of 25 m (identical to laboratory ice). Dotted lines show Monte Carlo predictions for peak absorption lengths of 18 m and 12 m. The error bars show only statistical uncertainties in the observed rates and in the Monte Carlo rates.

observed presence of impurities in the butyl acetate used) would tend to reduce the predicted Monte Carlo rates, so our results should be regarded as a lower limit to the optical clarity of the ice. It should also be pointed out that the large absorption length implied by these results indicates that PMT size, rather than the optical quality of the ice, will be the limiting factor for a real neutrino detector: this is because for a smaller PMT, loss of light due to angular spread of the Cerenkov cone outweighs the loss of light due to optical absorption of the ice. Finally, because the ionic purity and particulate concentration of the Greenland ice are comparable to those measured for distilled water, it is not surprising that the optical properties of the two substances are also comparable. Trodahl and others[8] have studied the diffusive transport of light through bubbly sea ice and conclude that the optical absorption length at a wavelength of 500 nm must be at least 10 m; as this ice contains brine pockets and algae, the pure ice found in the interior of Greenland or Antarctica should be much better for our purposes.

We find these results very encouraging, and are planning more extensive experiments at the South Pole during the coming austral summer (November 1991–January 1992), in particular the operation of one or two strings, each with four 20-cm-diameter PMTs at a depth of ~1 km, where the ice is expected to be bubble free[9]. Assuming that these tests are successful, we then hope to begin construction and installation of full-size strings of twenty 20-cm-diameter PMTs in the succeeding season (1992-93). In addition, as part of this year's work, we will be investigating the possibility of using our detection technique to construct muon detectors able to operate in conjunction with South Pole Air Shower Experiment, an existing air-shower array at the South Pole[10]. The large effective muon-sensitive area of a PMT at shallower depths suggests that good muon coverage could be achieved with only a small number of drilled holes. □

Received 7 May; accepted 26 July 1991.

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ACKNOWLEDGEMENTS. We thank B. Koci and the entire PICO organization for the use of the borehole and for on-site assistance, E. K. Solarz and W. Williams for their help with the mechanical construction of the PMT string, J. Lynch and H. Zimmerman of the NSF, J. Learned for his sharing of DUMAND expertise, and E. Zeller of the University of Kansas for suggesting the idea of using South Pole ice in a neutrino telescope. This work was supported in part by the Division of Polar Programs of the US NSF and by the California Space Institute.

The superconducting energy gap of Rb_3C_{60}

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THE discovery of superconductivity in potassium-doped C_{60} (ref. 1) has been followed by an intense effort to understand the physics and chemistry of metal-doped fullerene solids[2–13]. Experimental studies of alkali-metal-doped C_{60} have now provided insight into the structure[7,13] and the coherence length and penetration depth[4] of the superconducting phase. No measurements of the superconducting energy gap (Δ) have, however, been reported. The BCS theory of superconductivity[15], which has been used to interpret much of this experimental work[2,4,9–13], predicts (in the limit of weak coupling) that the reduced energy gap $2\Delta/kT_c$ has a material-independent value of 3.53. Values in excess of 3.5 define strong coupling, and thus provide insight into the nature of the pairing mechanism. Here we describe the measurement of Δ for single-phase superconducting Rb_3C_{60} by tunnelling spectroscopy using a scanning tunnelling microscope. We obtain a value of Δ at 4.2 K of 6.6 ± 0.4 meV, corresponding to a reduced energy gap of 5.3. This is significantly larger than predicted by BCS theory, but similar in magnitude to values found for high-temperature copper oxide superconductors[14]. Our finding of strong coupling in Rb_3C_{60} suggests the need for caution in using standard BCS theory to interpret superconductivity in metal-doped C_{60}.

Tunnelling spectroscopy has been one of the most successful techniques used to probe conventional metal and alloy superconductors[16]. In particular, tunnelling spectra can provide values for both the energy gap Δ and the electron-phonon spectral function $\alpha^2F(\omega)$, where α^2 is a measure of the coupling and $F(\omega)$ is the phonon density of states. To obtain a clear value for Δ by tunnelling, it is essential to prepare a uniform insulating barrier between the superconductor and metal junction. As the C_{60} superconductors have short coherence lengths[4] and as the samples are inhomogenous, we expect that planar junctions might show significantly broadened gap features (even for the ideal BCS case). We have therefore used a low-temperature scanning tunnelling microscope (STM) to make point junctions with a sharpened metal tip. Point tunnelling spectroscopy has been used to measure Δ in a variety of superconducting materials, including pure metals[16], organics[17] and oxides[18], and the values of Δ determined by this technique for conventional superconductors are comparable to those obtained with planar junctions.

The Rb_3C_{60} samples were prepared by methods described in detail elsewhere[12]. Briefly, purified and dried C_{60} was reacted with RbHg in a 1:3 ratio at 200 °C for 8-72 h. After this initial reaction, the superconducting fraction determined from shielding measurements was typically >35%. The resulting powder was then ground, pressed into a pellet, and sintered at 200 °C for 3-12 h. Diamagnetic shielding measurements made on these sintered pellets show that the superconducting fraction can

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